Environmental radioactitivy in Denmark in 1978

Aarkrog, A.; Bøtter-Jensen, Lars; Dahlgaard, Henning; Hansen, Heinz Johs. Max; Lippert, Jørgen Emil; Nielsen, Sven Poul; Nilsson, Karen

Publication date:
1979

Document Version
Publisher's PDF, also known as Version of record

RISØ

Risø-R-403

Environmental Radioactivity in Denmark in 1978

A. Aarkrog, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen, J. Lippert, S. P. Nielsen, and Karen Nilsson

Risø National Laboratory, DK-4000 Roskilde, Denmark
June 1979

Risø-R-403

ENVIRONMENTAL RADIOACTIVITY IN DENMARK IN 1978

A. Aarkrog, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen,
J. Lippert, S.P. Nielsen and Karen Nilsson

Abstract. Strontium-90 was determined in samples from all over the country of precipitation, ground water, sea water, grass, dried milk, grain, bread, potatoes, vegetables, fruit, total diet, and human bone. Furthermore, ^{90}Sr was determined in local samples of air, rain water, grass, sea plants, fish, and meat. Cesium-137 was determined in soil, sea water, milk, grain products, potatoes, vegetables, fruit, total diet, fish, and meat. It was also measured by wholebody-counting of a control group at Risø Health Physics Department. Estimates of the mean contents of radiostrontium and radiocesium in the human diet in Denmark during 1978 are given. The γ-background was measured regularly by TLD, ionization chamber and on site γ-spectroscopy at locations around Risø, at ten of the State experimental farms along the coasts of the Great Belt and around Gyllingnæs. The marine environments at Barsebäck and Ringhals were monitored

June 1979
Risø National Laboratory

for ^{137}Cs and corrosion products (^{58}Co, ^{60}Co, ^{65}Zn, ^{54}Mn). Results of plutonium determinations in soil and sediments from 1978 are presented in this report. Tritium was determined in groundwater and precipitation. Finally the report includes routine surveys of environmental samples from the Risø area.

INIS-descriptors:

[0] DENMARK, ENVIRONMENT, EXPERIMENTAL DATA, RADIOACTIVITY, TABLES

[1] AIR, ATMOSPHERIC PRECIPITATIONS, BONE TISSUES, BREAD CEREALS, DIET, FALLOUT DEPOSITS, FISHES, FOOD CHAINS, FOODS, GLOBAL FALLOUT, GRAMINEAE, GROUND WATER, MEAT, MILK, POTATOES, RAIN WATER, SEEDS, SEAWATER, STRONTIUM 90

[2] BREAD, CEREALS, CESIUM 137, DIET, FALLOUT DEPOSITS, FISHES, FOOD CHAINS, FRUITS, GLOBAL FALLOUT, MEAT, MILK, POTATOES, SEAWATER, SEEDS, SOILS, WHOLE-BODY COUNTING

[3] AQUATIC ECOSYSTEMS, BARSEBAECK-1 REACTOR, BARSEBAECK-2 REACTOR, CESIUM 137, COBALT 58, COBALT 60, FALLOUT DEPOSITS, LOCAL FALLOUT, MANGANESE 54, RINGHALS-1 REACTOR, RINGHALS-2 REACTOR, RINGHALS-3 REACTOR, ZINC-65

[4] FALLOUT DEPOSITS, GLOBAL FALLOUT, PLUTONIUM, PLUTONIUM ISOTOPES, SEAWEEDS, SEDIMENTS

[5] ATMOSPHERIC PRECIPITATIONS, GROUND WATER, SOILS, TRITIUM

[6] BARSEBAECK-1 REACTOR, BARSEBAECK-2 REACTOR, LOCAL FALLOUT RISOE NATIONAL LABORATORY

[7] BACKGROUND RADIATION, RISOE NATIONAL LABORATORY

UDC 614.73(489)

ISBN 87-550-0594-2
ISSN 0106-2840
ISSN 0106-407X

Risø Repro 1979

CONTENTS

Page

Page

ABBREVIATIONS AND UNITS

J: joule: the unit of energy; 1 J = 1 Nm (= 0.239 cal)
Gy: gray: the unit of absorbed dose = 1 J kg^{-1} (= 100 rad)
Sv: sievert: the unit of dose equivalent = 1 J kg^{-1} (= 100 rem)
Bq: becquerel: the unit of radioactivity = 1 s^{-1} (= 27 pCi)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: $3.7 \cdot 10^{10}$ Bq (= $2.22 \cdot 10^{12}$ dpm)

T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
m: milli: 10^{-3}
μ: mikro: 10^{-6}
n: nano: 10^{-9}
p: pico: 10^{-12}
f: femto: 10^{-15}
a: atto: 10^{-18}

cap.: caput: (per individual)
TNT: trinitrotoluol; 1 Mt TNT: nuclear explosives equivalent to 10^{9} kg TNT.

cpm: counts per minut
dpm: disintegrations per minut
OR: observed ratio
CF: concentration factor
FP: fission products
μR: micro-roentgen, 10^{-6} roentgen
S.U.: pCi ^{90}Sr (g Ca)$^{-1}$
O.R.: observed ratio
M.U.: pCi ^{137}Cs (g K)$^{-1}$

V: vertebrae
m: male
f: female
nSr: natural (stable) Sr

eqv. mg KCl: equivalents mg KCl: activity as from 1 mg KCl (~0.88 dpm)

S.D.: standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$

S.E.: standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$

U.C.L.: upper control level
L.C.L.: lower control level
Δ: one standard deviation due to counting
S.S.D.: sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$
f: degrees of freedom
s^2: variance
v^2: ratio between the variance in question and the residual variance
P: probability fractile of the distribution in question
η: coefficient of variation, relative standard deviation
anova: analysis of variance
A: relative standard deviation 20-33%
B: relative standard deviation >33%, such results are not considered significantly different from zero activity
B.D.L.: below detection limit

In the significance test the following symbols were used:
* : probably significant (P > 95%)
** : significant (P > 99%)
***: highly significant (P > 99.9%)

Samples:

H: sea water
J: soil
L: air
B: bed soil
Å: eel
PG: grass

PH:	sea plants
D:	drain water
S:	waste water
R:	precipitation
M:	milk

1. INTRODUCTION

1.1.

The present report is the twenty-second of a series of periodic reports (cf. ref. 1) dealing with measurements of radioactivity in Denmark. The organization of the material in the present report corresponds to that of last years report. After the introduction and a chapter on organization and facilities there follows a chapter on environmental monitoring around nuclear facilities (Risø, Barsebäck and Ringhals). Chapter four deals with fallout nuclides in the abiotic environment, i.e., air, water and soil. Chapters five and six comprise fallout nuclides in the human diet and human tissues, respectively. Chapter seven is devoted to environmental tritium studies. Plutonium and americium in environmental samples are treated in chapter eight, and external radiation in chapter nine. The names of the authors of each chapter appear at its head.

1.2.

The methods of radiochemical analysis[2-4] and the statistical treatment of the results [12] are still based on the principles established in previous reports[1].

1.3.

The report does not include detailed tables of the total β-measurements originating from the environmental control of the Risø site. These tables are available in the form of micro-cards at the Risø library.

1.4.

The report contains no information on sample collection and analysis except in cases where these procedures have been altered.

1.5.

In 1978 the personnel of the Environmental Control Section of the Health Physics Department consisted of two chemists, one biologist, eight laboratory technicians, two sample collectors, and two laboratory assistants. The Section for Electronics Development continued to give assistance with the maintenance of counting equipment, with the interpretation of γ-spectra and with data treatment. The program (cf. 2) used in the calculations of ^{90}Sr and the γ-analysis, as well as the program for data treatment, were developed by this Section.

1.6.

The composition of the average Danish diet used in this report is identical with that proposed in 1962 by Professor E. Hoff-Jørgensen, Ph.D.

2. FACILITIES[1,6,7,8]

By J. Lippert

2.1. Detectors

The activity of the samples is measured as follows:

Alpha (^{239}Pu, ^{241}Am): 16 solid-state surface barrier detectors connected to four multichannel analyzers (64 channels per detector).

Beta (^{90}Y mainly): 5 low-level gas-flow Geiger counters, 4 of them provided with automatic sample chambers. Two new "multi-detector"-systems each containing 5 sample counters and a common anticoincidence shield are now put into regular use. This type of detector is intended to replace the mechanical sample changers after a test period.

Gamma (natural and fallout isotopes): 5 Ge(Li) detectors in 10 cm lead shields and connected to five 1024-channel analyzers. One further Ge(Li) detector mounted on a tripod and a 4096-channel analyzer are used for field measurements, and a 8" x 4" NaI(Tl) in an underground shielded room is used for whole-body counting.

2.2. Data treatment

Measured spectra are evaluated directly on a desk-top calculator or transferred to a Burroughs B6700 computer.

A program system STATDATA[16] is developed for registration and treatment of environmental measurements including multichannel analyzer spectra. To date, approximately 45 000 sets of results have been registered covering the period from 1957.

3. ENVIRONMENTAL MONITORING AT RISØ, BARSEBÄCK AND RINGHALS IN 1978

by H. Dahlgaard

3.1. Gross β-activity at Risø

3.1.1. Sea water

Fig. 3.1.1.1 shows the sample locations in Roskilde Fjord. The yearly mean for H I in 1978 was 59 eqv. mg KCl (2.5 g)$^{-1}$ (in 1977: 60), for H III-VI: 60 eqv. mg KCl (2.5 g)$^{-1}$ (in 1977: 60) and for H VII-X: 59 eqv. mg KCl (2.5 g)$^{-1}$ (in 1977: 60). Fig. 3.1.1.2 shows the mean levels of radioactivity in sea salt since 1957.

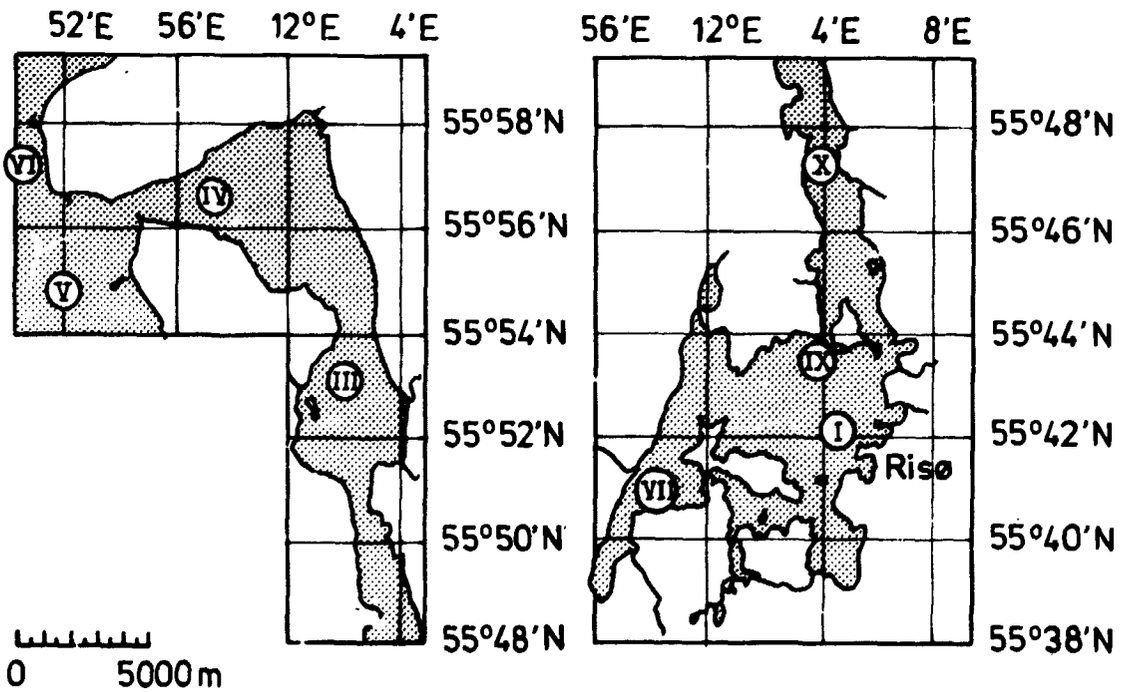

Fig. 3.1.1.1. Roskilde Fjord.

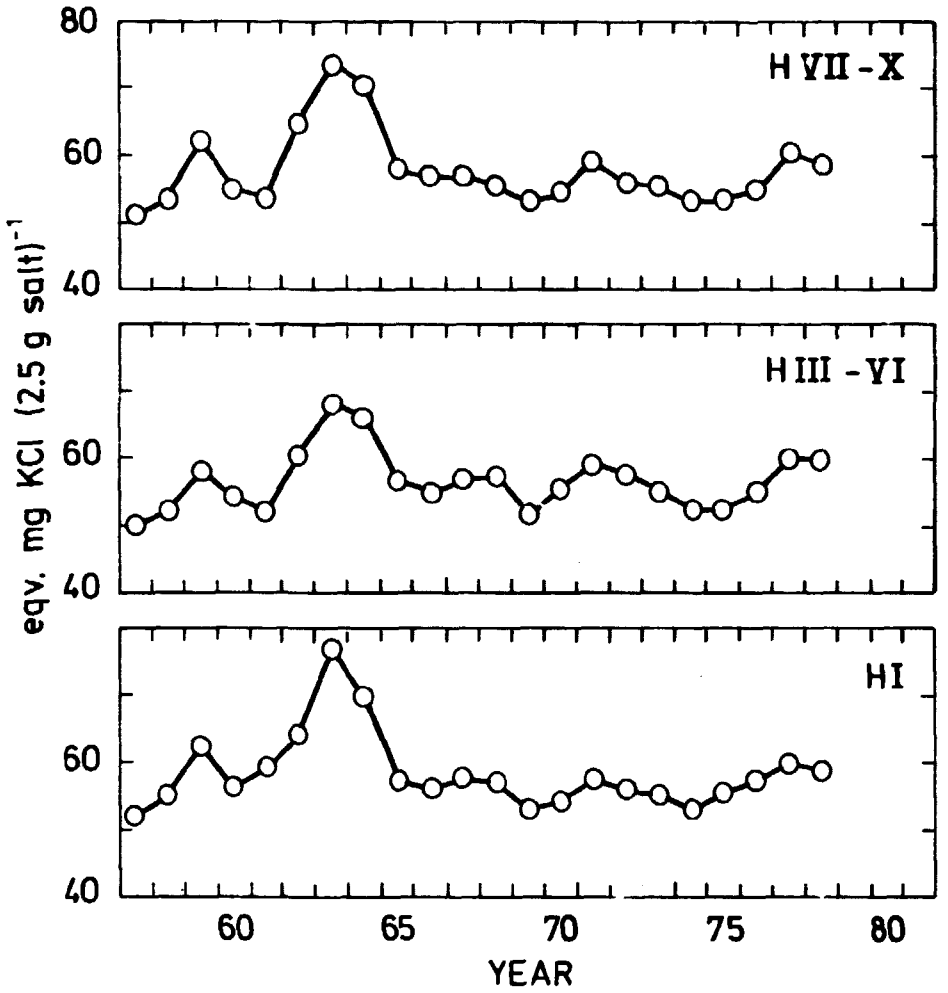

Fig. 3.1.1.2. Mean radioactivity ir sea water 1957-1978.

3.1.2. Soil

No soil samples from the environment of Risø were measured for total β-activity in 1978.

3.1.3. Air

The mean value for the year was 0.18 eqv. mg KCl m^{-3} as compared with 0.22 eqv. mg KCl m^{-3} in 1977.

Fig. 3.1.3.1 shows the mean FP levels in air since 1957.

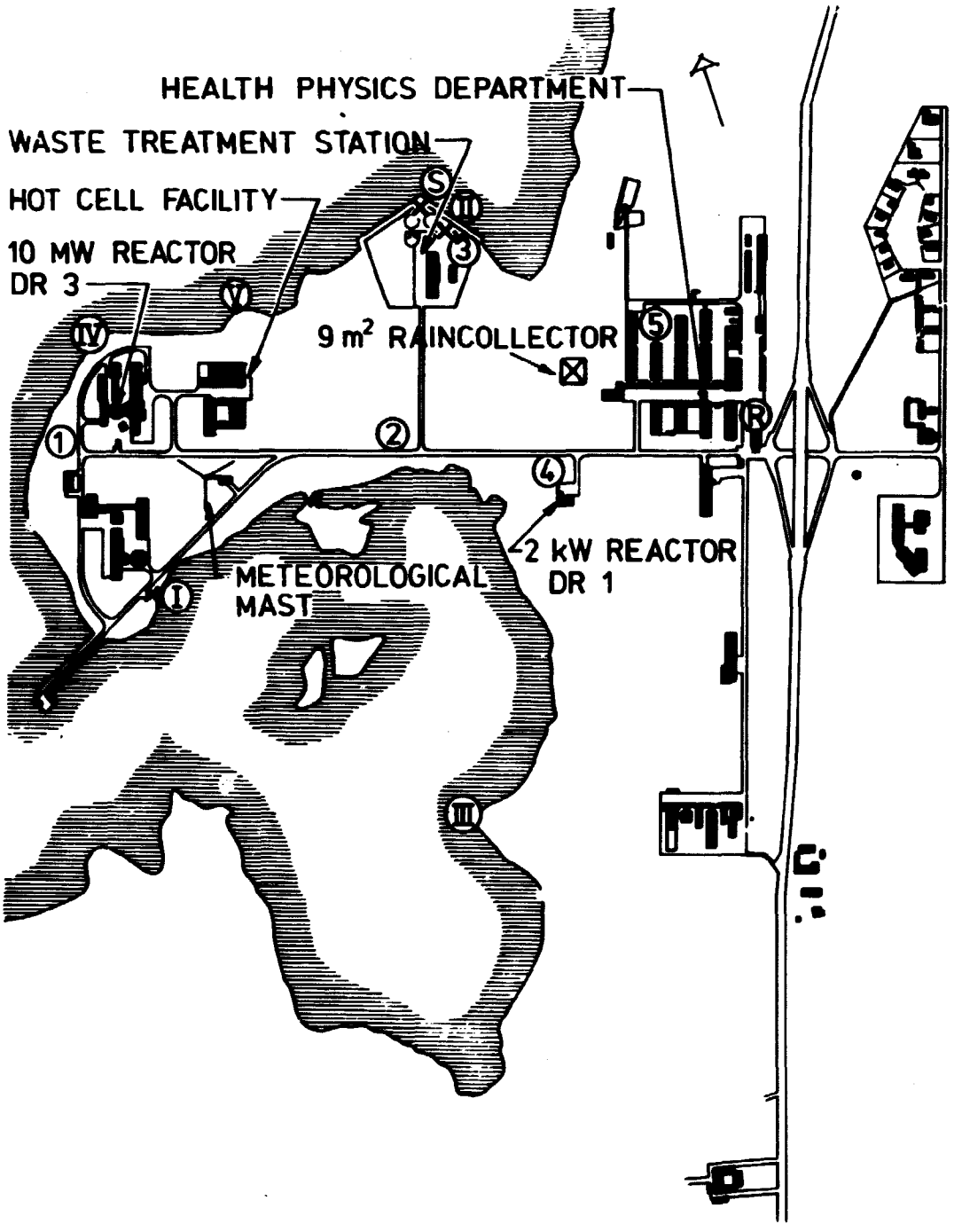

Fig. 3.1.2.1. Sampling locations at Risø National Laboratory. 1-5: locations for rainbottels (0.03 m^2 each), ionexchange collumns (0.06 m^2 each) and grass samples. I-V: sampling locations for drainige water. S: sewage water. R: 1 m^2 daily raincollector. X:9 m^2 monthly ionexchange raincollector.

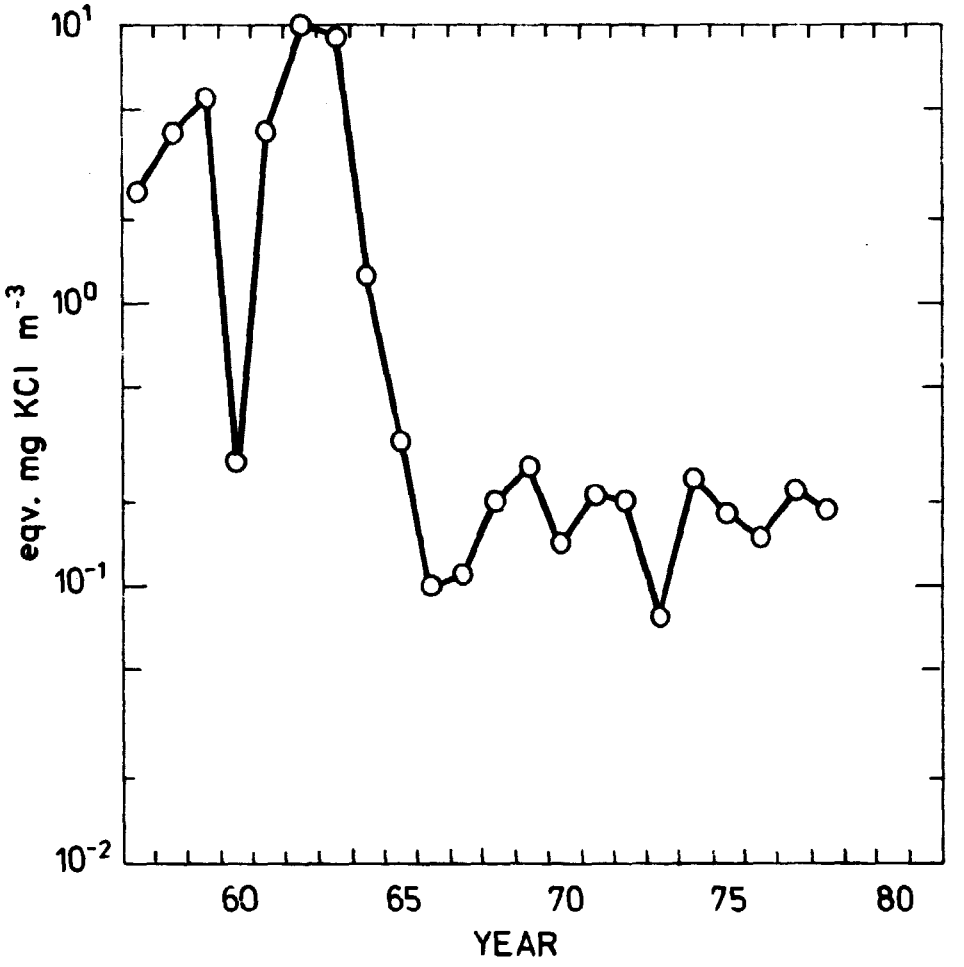

Fig. 3.1.3.1. Mean radioactivity in air, 1957-1978.

3.1.4. Sediment samples from Roskilde Fjord

The mean activity in sediment B I was 164 eqv. mg KCl (3.0 g ash)$^{-1}$ in 1978 as compared with 162 eqv. mg KCl (3.0 g)$^{-1}$ in 1977. Fig. 3.1.4.1 shows the mean levels for B I since 1957 (cf. also 3.4).

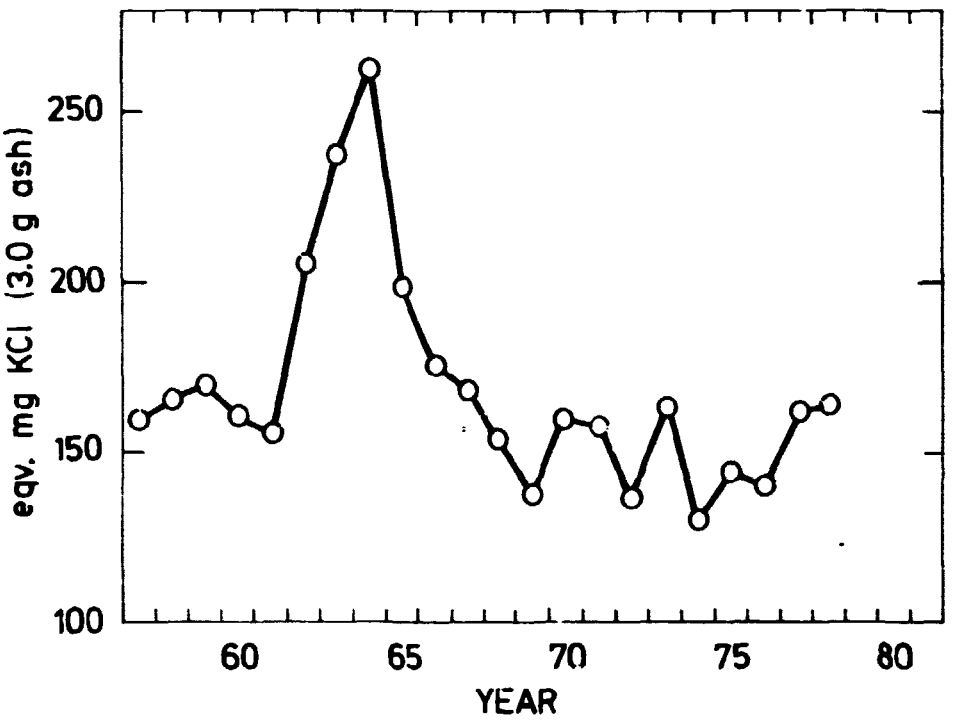

Fig. 3.1.4.1. Mean radioactivity in sediment samples (BI), 1957-1978.

3.1.5. Fish

No fish samples from Roskilde Fjord were measured for total β-activity in 1978.

3.1.6. Grass

The mean values were in 1978 for PG I: 18 eqv. mg KCl (0.1 g grass ash)$^{-1}$ (in 1977: 23), for PG II-III: 14 eqv. mg KCl (0.1 g)$^{-1}$ (in 1977: 22) and for PG IV-V: 22 eqv. mg KCl (0.1 g)$^{-1}$ (in 1977: 19). Fig. 3.1.6.1 shows the mean activities in grass ash since 1957.

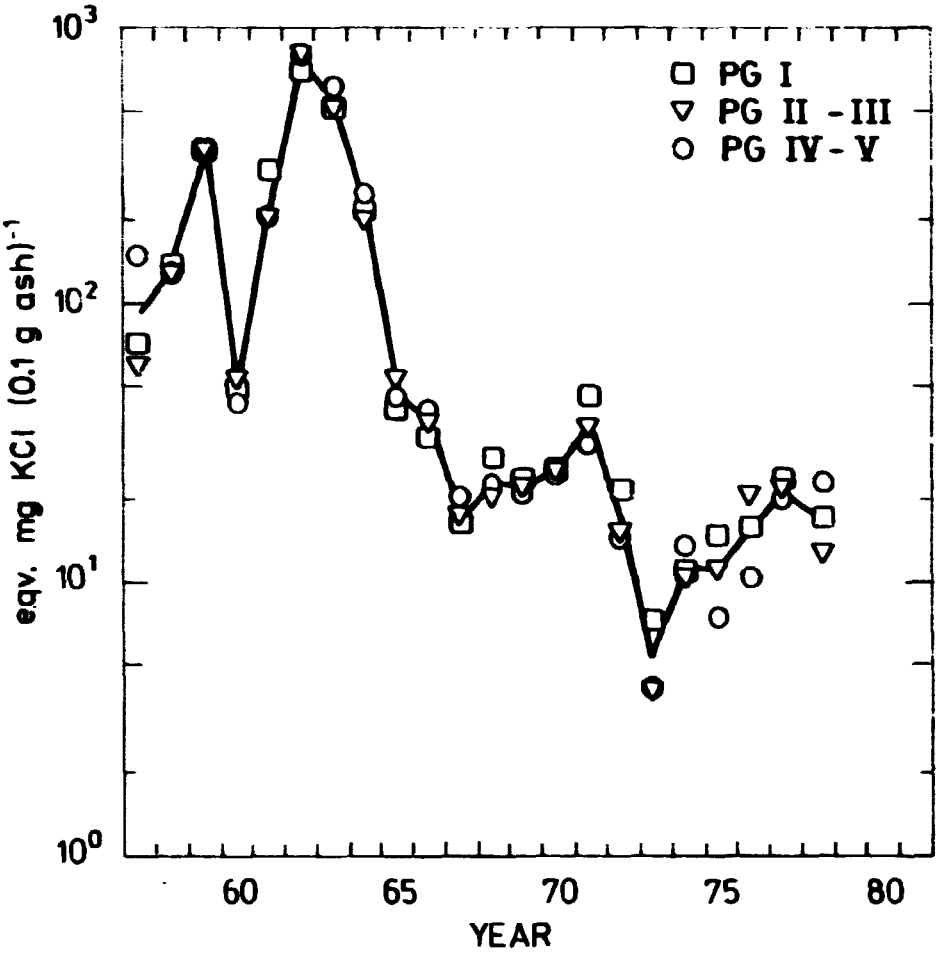

Fig. 3.1.6.1. Mean FP-radicactivity in grass ash, 1957-1978.

3.1.7. Sea plants

The mean FP level in 1978 in Fucus vesiculosus (PH I) was 1 eqv. mg KCl (0.1 g ash)$^{-1}$ (6 in 1977). In Zostera marina (PH III-IX) we found 1 eqv. mg KCl (0.1 g ash)$^{-1}$ in 1978 (4 in 1977).

3.1.8. Fresh water

Fig 3.1.8.1 shows the control chart for S (cf. fig. 3.1.2.1). The yearly means for D I, D II, D IV, and S in 1978 were 26 eqv. mg KCl l^{-1} (1977: 57), 19 eqv. mg KCl l^{-1} (1977: 19), 60 eqv. mg KCl l^{-1} (1977: 16), and 41 eqv. mg KCl l^{-1} (1977: 52) respectively. Fig. 3.1.8.2 shows the activity in drainage water (D) and sewage water (S).

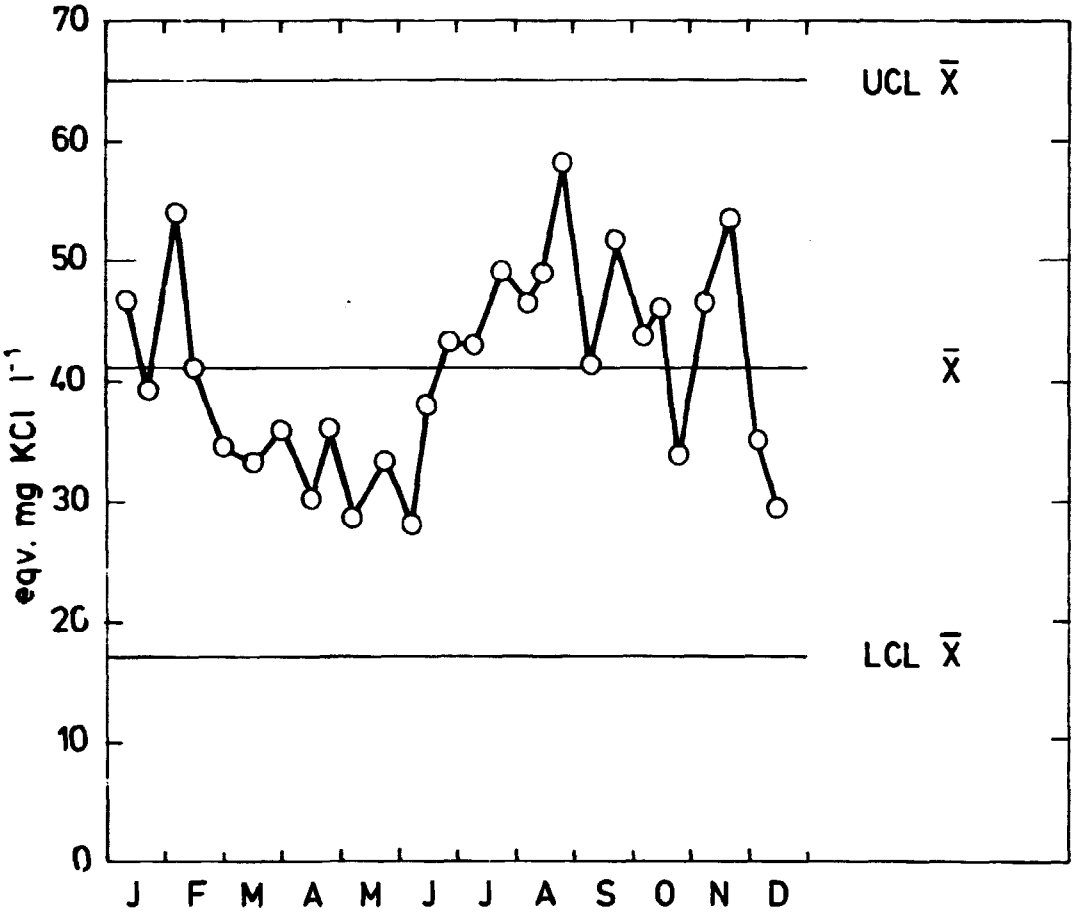

Fig. 3.1.8.1. Control chart for sewage water (S) 1978.

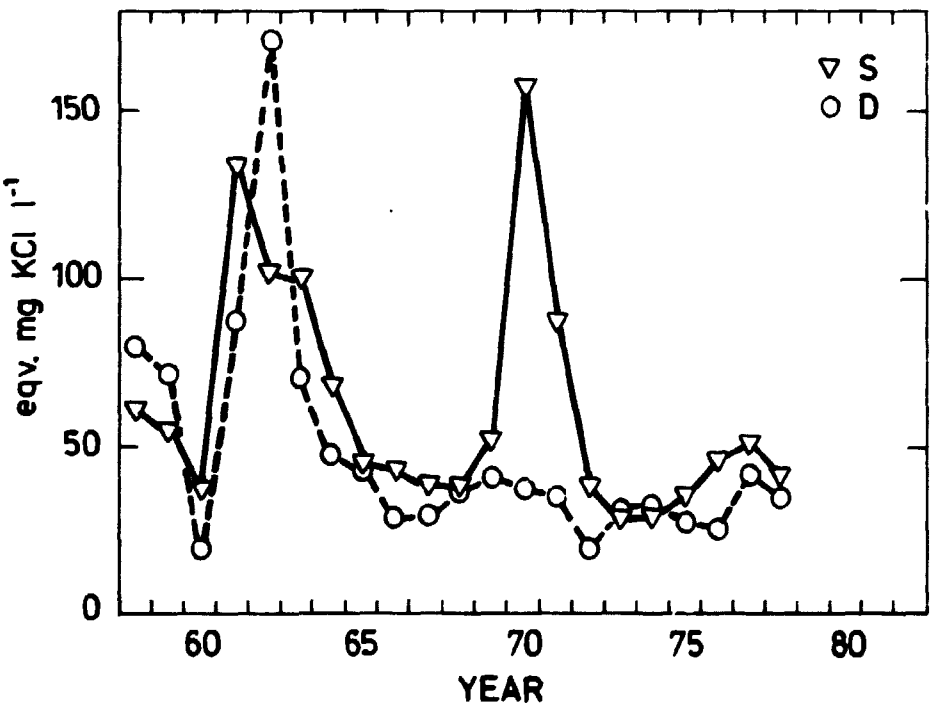

Fig. 3.1.8.2. Annual total-β mean levels in waste water (S) and drain water (D) collected at Risø 1958-1978.

3.1.9. Rain water

The total fallout in 1978 was measured at $0.021 \cdot 10^6$ eqv. mg KCl m^{-2}, and the annual mean concentration in rain water at Risø was 40 eqv. mg KCl l^{-1}. In 1977 the corresponding figures were $0.021 \cdot 10^6$ and 76 respectively.

Fig. 3.1.9.1 shows the specific activity in rain water since 1957.

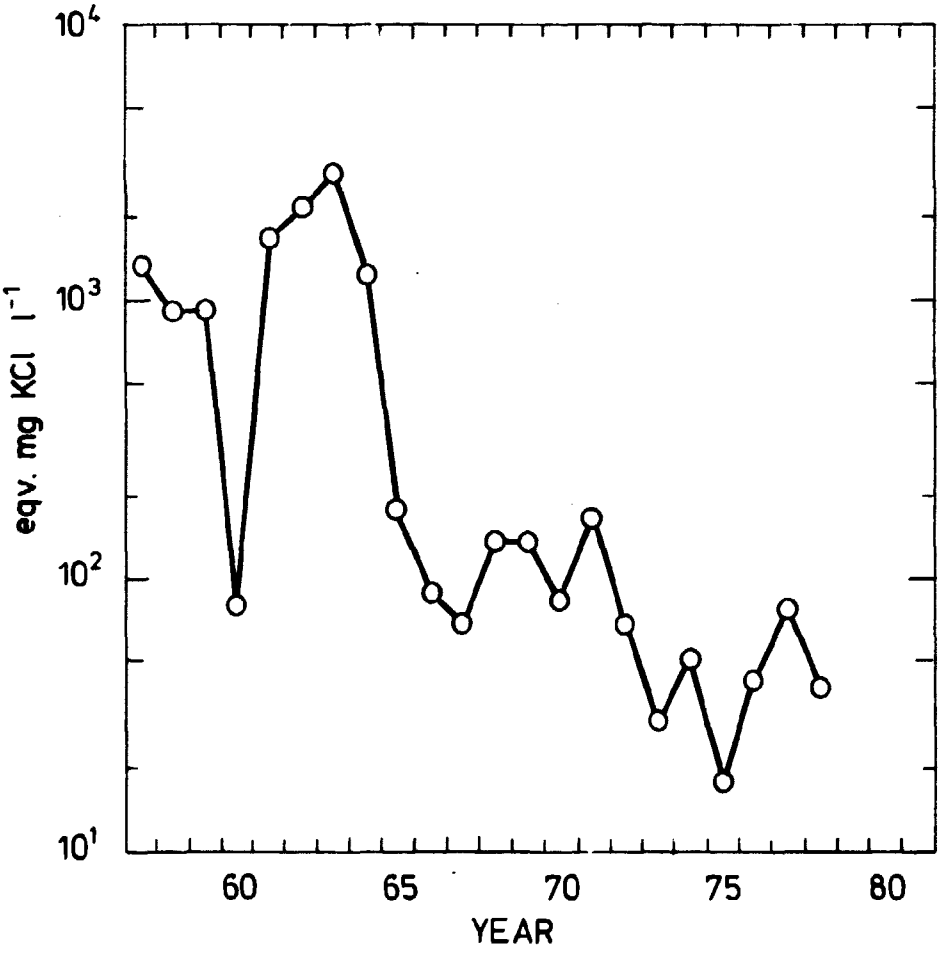

Fig. 3.1.9.1. Specific activity in precipitation, 1957-1978.

3.2. Marine environmental monitoring at Barsebäck and Ringhals

The radiological monitoring of the marine environment around the two nuclear power plants at Barsebäck and Ringhals in Sweden (Risø Report No. 386)[1] was continued in 1978.

Figures 3.2.1.1 and 3.2.1.2 show the sampling locations.

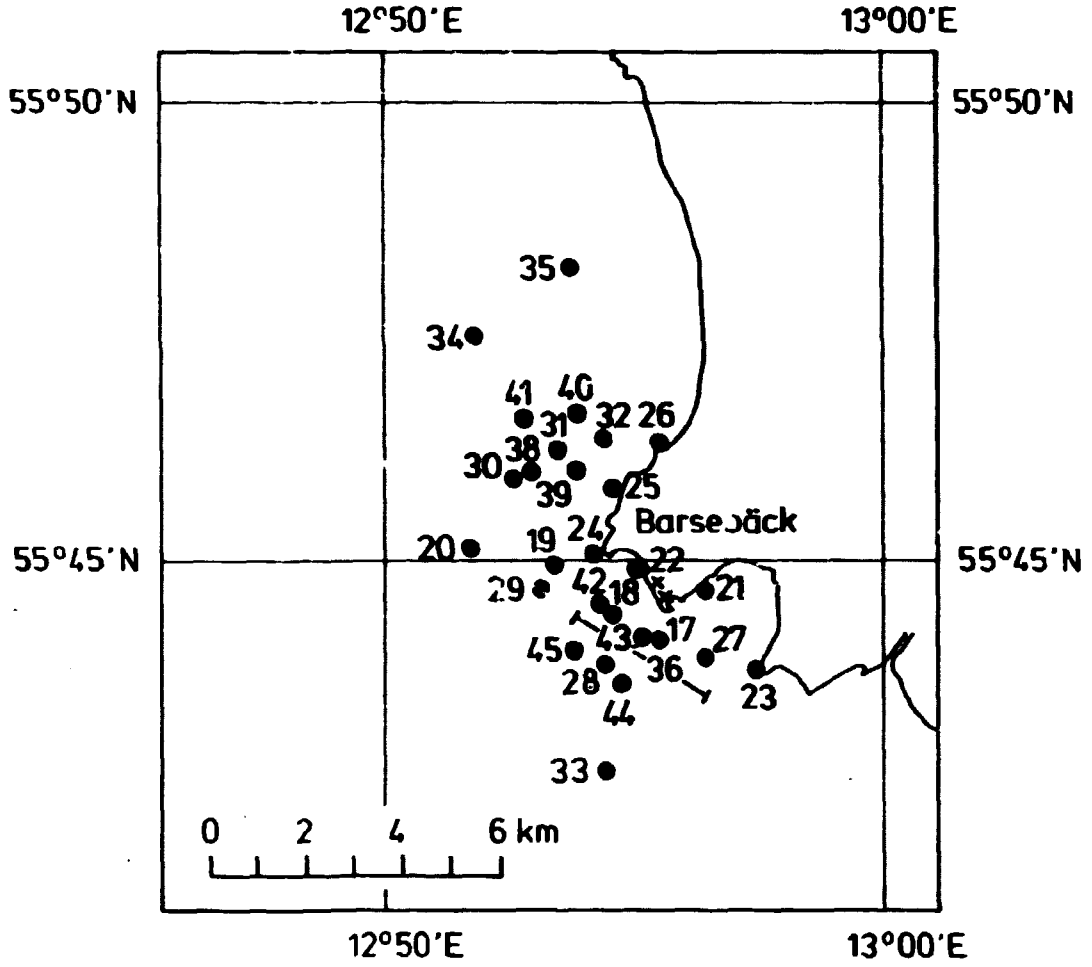

Fig. 3.2.1.1. Sampling locations at Barsebäck.

This programme is sponsored by Nordic Liaison Committee for Atomic Energy (Nordisk kontaktorgan for Atomenergi) as part of a co-operative activity together with the Department of Radiation Physics, University of Lund, Sweden.

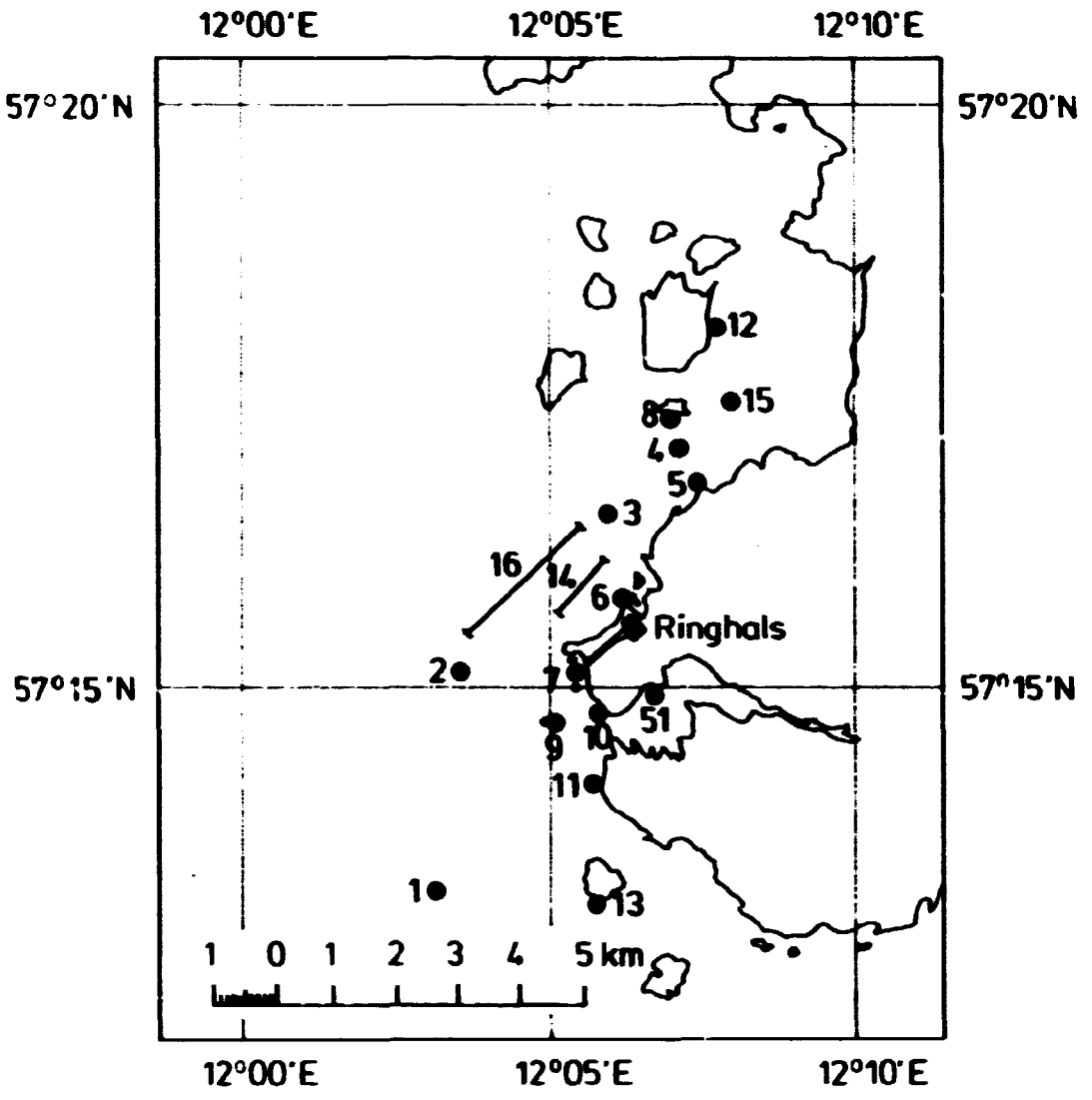

Fig. 3.2.1.2. Sampling locations at Ringhals.

3.2.1. γ-emitting radionuclides in brown algae and eel grass

Tables 3.2.1.1, 3.2.1.2 and 3.2.1.3 show the radionuclide concentrations found by γ-spectrometric analysis in brown algae at Barsebäck and Ringhals in 1978.

As noted earlier the decrease in concentration with distance from the outlet is similar for the reactor-produced nuclides ^{60}Co, ^{58}Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag and ^{51}Cr.

Table 3.2.1.1. Gamma-emitting radionuclides in Fucus vesiculosus collected at Barsebäck in 1978
(Unit: pCi kg^{-1} fresh weight)

Date of sampling	17 April						15-16 June					8 September						10 December
Station** No.	22	24	25	26	21*	23*	22	24	25	26	23*	22	24	25	26	21*	23*	24
Distance from outlet in km	0.6	1.4	2.9	4.0	1.5	2.8	0.6	1.4	2.9	4.0	2.8	0.6	1.4	2.9	4.0	1.5	2.8	1.4
^{60}Co	5,090	2,720	1,310	856	553	231	8,350	5,470	1,600	780	406	24,600	14,700±1,200	3,320	1,490	1,710	667	36,800
^{58}Co	482	228	90	60	35	11.5	2,320	1,070	358	134		14,540	9,040±740	1,870	863	1,060	408	8,380
^{54}Mn	225	134	61	38	25	10.4	576	382	108	61	25 A	1,400	775± 47	172	103	153	53	1,300
^{65}Zn	1,120	713	277	186	96	58	1,500	879	267	144		4,760	2,640±220	655	219	212	144	7,920
^{110m}Ag		26 B	19 A									393						225
^{51}Cr	238	79 A					98					1,080						
^{137}Cs	93			71	53	44	130	113	82	77	92		82± 33	94	66	60	63	
^{131}I	47	34		20 A	16 B	20	46	50						21				
^{95}Zr		31 A	43	49	48	28												

* Locations south of the outlet; the other locations were situated north of the outlet.
**Cf. Fig. 3.2.1.

Table 3.2.1.2. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Ringhals May 20, 1978. (Unit: pCi kg^{-1} fresh weight)

Station** No.	7	6	5	8	12	10*	9*	11*	13*
Species	Fu.se.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.se.	Fu.se.	Fu.se.	Fu.se.
Distance from outlet in km	0.2	1.9	4.1	4.8	6.3	0.9	1.1	1.9	4.1
^{60}Co	2270	373	267	118	67	887	530	896	145
^{58}Co	951	155	120	52	26	192	309	167	38 A
^{54}Mn	233	52	49	21	16	61	56	88	1 A
^{65}Zn	2810	418	242	113	76	1300	517	1034	185
^{110m}Ag	241	25 A				102		51 A	
^{137}Cs			58	53	46		105		51
^{131}I				23 A					
^{95}Zr		22 A		8 A	37		46 A	65 A	59 A

* Locations south of the outlet; the other locations were situated north of the outlet.
**Cf. Fig. 3.2.2.

The decrease in concentration 125 km along the Swedish west coast north of the Barsebäck outlet was described in 1977 and 1978 by a power function: $A = k\ X^{-1.4 \pm 0.1}$, where A is the activity concentration and X is the distance in km[32]. In 1978 the decrease between 0.6 and 4 km was described more adequately by an exponential equation: $A = k\ e^{-0.7\ X}$.

This last equation is not expected to be valid beyond 4 km, however.

On September 8, 1978 18 pCi kg^{-1} (fresh) of ^{58}Co was detected in Fucus serratus from Skovshoved (Denmark) 20 km west of the outlet. This indicates that in spite of the predominant northbound surface current in the Sound minor amounts of activity from Barsebäck may reach the Danish coast.

At Ringhals the decrease with distance is much more variable (table 3.2.1.2 and 3.2.1.3).

Table 3.2.1.3. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.), Fucus spiralis (Fu.sp.) and Ascophyllum nodosum (As.no.) collected at Ringhals September 1978. (Unit: pCi kg^{-1} fresh weight)

Station** No.	7 East	7 East	7 South	7 South	7 South	6	5	8	12	9*	11*	51*	13*	37*
Species	Fu.ve.	As.no.	Fu.ve.	Fu.sp.	Fu.se.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.ve.
Distance from outlet in km	0.2	0.2	0.2	0.2	0.2	1.9	4.1	4.8	6.3	1.1	1.9	2.0	4.1	19.4
^{60}Co	2,070	3,830	1,320	1,950	2,170	274	105	95	80	273	422	491	40	12.0 A
^{58}Co	1,010	591	538	901	551	55	37	30	34	111	127	187	10.3	9.8 A
^{54}Mn	267	115	170	367	203	38	22 A	19 A	25 A	34	76	54	8.5	
^{65}Zn	14,560	11,830	6,290	10,400	6,650	389	481	252	229	1,320	1,190	1,560	134	
^{110m}Ag	1,580	1,190	610	660	530	52	69	42 A	37 A	52	81 A	72 A	15 A	
^{51}Cr			210 A		110 B	66 A								
^{137}Cs														54
^{131}I	292	359	69	230 B	69	12 B								
^{95}Zr	93 B		78		73	57							13 A	13 A

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

For the 1977 (Risø Report 386)[1] and 1978 results (except location 51 and 37) the decrease can be approximately expressed with a power function: $A = k\ X^{-0.79 \pm 0.04}$ in the northern direction and $A = k\ X^{-0.96 \pm 0.06}$ in the southern direction. An extrapolation 19.4 km south from the outlet gives values 3-6 times higher than the concentrations actually found (location 37, Varberg), indicating that these equations are not to be used outside the sampling area.

A minor part of the ^{54}Mn activity originates from fallout. Thus Fucus vesiculosus sampled at Sjællands Rev ($55^{o}58'N$, $11^{o}22'E$) on November 24, 1978 showed a ^{54}Mn content of 9 pCi kg^{-1} (fresh weight).

The nuclides ^{95}Zr, ^{131}I and ^{137}Cs show no decrease with distance from the outlet. Part of these nuclides probably originates from the power plants (see e.g. ^{131}I, Ringhals, September 1978), but the major portion of the activity comes from fallout. ^{131}I might also originate from hospital discharges.

At one occasion four different fucoids were sampled in order to investigate species differences (see table 3.2.1.3, location 7). As the distance between 7 East and 7 South is approximately 20-30 m, the marked difference in nuclide concentrations in Fucus vesiculosus from these two subsites might be explained, e.g., by current differences.

This makes the species-comparison questionable, but apparently $^{60}Co/^{58}Co$-ratios are increasing in the order Fucus vesiculosus ∿ Fucus spiralis < Fucus serratus < Ascophyllum nodosum, indicating an increase in "integration time" in the same manner (see later). A comparison of the absolute concentrations makes it likely that Ascophyllum concentrates ^{54}Mn less than does Fucus vesiculosus and that the more delicate Fucus spiralis generally contains higher concentrations of all nuclides than Fucus vesiculosus.

The only obvious difference between Fucus serratus and Fucus vesiculosus is the higher concentration in Fucus serratus of the relatively longlived ^{60}Co explained by longer "integration time".

At one occasion, September 9th 1978, the eel-grass species Zostera nana was sampled at Barsebäck location 26. The activity concentration ratio Zostera/Fucus vesiculosus was 0.85 for ^{60}Co, 0.96 for ^{58}Co, 0.80 for ^{54}Mn and 1.70 for ^{65}Zn indicating a remarkable similarity with Fucus concerning uptake of cobalt and manganese, while Zn occurs at a higher concentration. However the consistency of these results and the comparisons of different fucoid species is to be investigated by further sampling.

Transfer factors:

$$TF = \frac{A_i}{\frac{1}{m}\sum_{m} D_j} \quad (pCi\ month\ kg^{-1}\ mCi^{-1})$$

and decay-corrected transfer factors:

$$DTF_m = \frac{A_i}{\sum_{m} D_j\ e^{-\lambda(i-j)}} \quad (pCi\ (m\ months)\ kg^{-1}\ mCi^{-1})$$

where A_i is the activity of a sample collected in month i (pCi kg^{-1} fresh weight), D_j is the discharge during month j (mCi $month^{-1}$), m is the number of months in the calculation and λ is the radioactive decay constant ($month^{-1}$) have been reported from this investigation earlier[1,32,33]. However, concerning the normal transfer factor TF, i.e. the ratio between activity in the sample and the mean monthly discharge without decay-correction, different numbers of months, m, have been used in the calculations.

Due to seasonal oscillations in the discharged amounts of activity this is of some importance. The decay-corrected transfer factors indicate that Fucus integrates discharges over 3-12 months (see below). However, as a reasonable compromise it is now decided to average discharges over the preceding 12 months in the TF calculations (table 3.2.1.4 and 3.2.1.5). The locations reported were chosen to avoid problems of fluctuations very near the outlet.

Table 3.2.1.4. Transfer factor, TF, without decay-correction. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet

Isotope	Sampling date	Discharge the preceding 12 months		TF
		mCi month^{-1}	rel. SD.%	pCi month kg^{-1} mCi^{-1}
^{60}Co	17/4-78	83.2	79.0	32.7
- " -	15/6-78	98.7	57.2	26.1
- " -	8/9-78	127.6	69.2	125
- " -	10/12-78	120.6	79.4	305
Mean	1978			122±65
Mean	1977			168±46
^{58}Co	17/4-78	30.7	72.8	7.4
- " -	15/6-78	41.0	76.8	26.0
- " -	8/9-78	76.2	118	128
- " -	10/12-78	76.3	119	110
Mean	1978			68±30
Mean	1977			75±25
^{54}Mn	17/4-78	5.8	67.1	23.1
- " -	15/6-78	7.0	58.0	54.6
- " -	8/9-78	9.8	79.5	83.9
- " -	10/12-78	6.8	96.8	148
Mean	1978			77±27
Mean	1977			133±25
^{65}Zn	17/4-78	19.8	99.0	36.0
- " -	15/6-78	21.8	85.0	40.3
- " -	8/9-78	26.1	89.5	109
- " -	10/12-78	23.2	99.9	341
Mean	1978			132±72
Mean	1977			157±43
^{110m}Ag	17/4-78	5.6	102	4.7
- " -	15/6-78	6.6	87.0	
- " -	8/9-78	7.8	77.6	
- " -	10/12-78	8.0	71.6	28.1
Mean	1978			16.4±11.7
Mean	1977			14.7±7.5
^{51}Cr	17/4-78	53.2	84.5	1.5
- " -	15/6-78	63.2	63.2	
- " -	8/9-78	91.5	84.9	
- " -	10/12-78	73.0	114	
Mean	1978			1.5
Mean	1977			5.6

The error term was ±1 SE.

Table 3.2.1.5. Transfer factor, TF, without decay-correction. Fucus vesiculosus collected at Ringhals, location 6, 1.9 km north of the outlet and location 9, 1.1 km south of the outlet

Isotope	Sampling date	Discharge the preceding 12 months		TF pCi month kg^{-1} mCi^{-1}	
		mCi $month^{-1}$	rel. SD.%	Location 6	Location 9
^{60}Co	20/5-78	205	124	1.82	2.58
- " -	4/9-78	228	108	1.20	1.20
Mean	1978			1.51±0.31	1.89±0.69
Mean	1977			4.09±0.56	6.90±0.90*
^{58}Co	20/5-78	126	148	1.23	2.45
- " -	4/9-78	118	146	0.47	0.94
Mean	1978			0.85±0.38	1.70±0.76
Mean	1977			1.21±0.67	2.50±1.02*
^{54}Mn	20/5-78	22.5	155	2.31	2.49
- " -	4/9-78	25.3	147	1.50	1.34
Mean	1978			1.90±0.40	1.92±0.58
Mean	1977			4.70±2.36	3.78±0.52*
^{65}Zn	20/5-78	93.8	178	4.46	5.51
- " -	4/9-78	84.4	101	4.61	15.66
Mean	1978			4.54±0.08	10.58±5.08
Mean	1977			12.9 ±7.9	22.7 ±10.2*
^{110m}Ag	20/5-78	5.46	157	4.58	
- " -	4/9-78	10.37	98.8	5.01	5.01
Mean	1978			4.80±0.22	5.01
Mean	1977			45.8	49.0*
^{51}Cr	20/5-78	359	241		
- " -	4/9-78	332	261	0.20	
Mean	1978			0.20	
Mean	1977				

*Fucus Serratus

The error term was ±1 SE.

Averages of these TF-values over a certain period of time combined with the relations to distance from the outlet described above are convenient when considering impact to the environment.

Differences between TF-values for ^{60}Co and ^{58}Co were expected due to differences in half-life (71 d. and 1922 d., respectively). At Barsebäck transfer factors for ^{60}Co, ^{54}Mn and ^{65}Zn are similar while those for ^{110m}Ag and ^{51}Cr are much lower. This is not the case at Ringhals, where ^{65}Zn and ^{110m}Ag are concentrated more than the other nuclides.

The reason for this is obscure, but several possibilities may be suggested, e.g. differences in physico-chemical state of the nuclides from the two plants, or environmental differences. However, as the TF-values from Ringhals are very variable, further investigations are necessary to confirm the quality of these findings.

The TF-values from Barsebäck (table 3.2.1.4) indicate a seasonal variation.

Part of this variation is, however, caused by a calculation artifact as discharges were considerably higher during July-November than in the first half of 1978.

Table 3.2.1.6. Decay-corrected transfer factors, DTF. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet. (Unit: pCi (m months) kg^{-1} mCi^{-1})

Date of sampling	770615	771022	771206	780417	780615	780908*	781210
m months	7.5	10.7	11.2	8	8	4	10
^{60}Co	28.0	20.6	19.8	3.33	8.13	22.5	29.9
^{58}Co	28.1	21.1	19.9	3.30	7.67	22.5	30.3
^{54}Mn	38.8	17.3	18.1	3.22	9.01	15.3	18.4
^{65}Zn	30.8	21.3	22.8	5.14	9.36	22.0	46.0
^{110m}Ag		3.90		0.66			3.74
^{51}Cr				0.77			

*Mean of 2 samples.

Decay-corrected transfer factors calculated for the number of months, m, that makes ^{60}Co and ^{58}Co values approximately equal, are reported in table 3.2.1.6. "m" is denoted the "integration time", as described previously[1,32,33].

These values elucidate the part of the seasonal variation, that is believed to be real. As the DTF-values are independent of the physical decay of the nuclides they are supposed to show the transfer of the metals independently of the decay-constants and ideally to be unaffected by oscillations in the rate of discharge[1,32,33].

Table 3.2.1.7. Decay-corrected transfer factors from Table 3.2.1.6. normalized to ^{60}Co

Date of sampling	770615	771022	771206	780417	780615	780908*	781210		
m months	7.5	10.7	11.2	8	8	4	10	Mean	S.E.
^{60}Co	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-
^{58}Co	1.00	1.02	1.00	0.99	0.94	1.00	1.01	0.99	0.010
^{54}Mn	1.38	0.84	0.91	0.97	1.11	0.68	0.62	0.93	0.098
^{65}Zn	1.10	1.03	1.15	1.55	1.15	0.98	1.54	1.21	0.089
^{110m}Ag		0.19		0.20			0.11	0.17	0.029
^{51}Cr				0.23				0.23	

*Mean of 2 samples.

The low DTF-values in April 1978 may be explained, e.g. by growth dilution. In the first months of 1978 currents were directed northwards along the Swedish coast approximately 75% of the time as usual[34], and activity ratios between samples north and south of the outlet were not altered. This indicates that the low DTF-values should not be explained by abnormal current conditions. However, investigations over some years are needed before a reliable description of a potential seasonal variation is possible.

DTF-values normalized to ^{60}Co are reported in table 3.2.1.7. These values indicate, as stated previously (Risø report 386)[1],

that uptake and elimination of radiocobalt, ^{54}Mn and ^{65}Zn in Fucus vesiculosus from Barsebäck might be similar. As mentioned above this is obviously not the case at Ringhals.

3.2.2. γ-emitting radionuclides in molluscs

In 1978 sampling of mussels from Barsebäck was unsuccessful. Results from Ringhals are reported in table 3.2.2.1. Activity ratios between Mytilus and brown algae sampled simultaneously are shown in table 3.2.2.2. Ratios are equal for the two cobalt isotopes indicating approximately the same "integration time" in Mytilus and Fucus. ^{65}Zn is concentrated to a higher level and ^{54}Mn to a lower level than ^{60}Co.

Table 3.2.2.1. Gamma-emitting radionuclides in molluscs (soft part) collected at Ringhals in 1978. (Unit: pCi kg^{-1} fresh weight)

Species	Date	Sampling locations	^{137}Cs	^{60}Co	^{58}Co	^{65}Zn	^{110m}Ag	^{54}Mn
Arctica islandica	22/5	16	19	16.9				
Mytilus edulis	20/5	8	27	37	20 B	54 A		
Mytilus edulis	20/5	5	31	46	32	88		
Mytilus edulis	20/5	7		429	181	99	125	14 A

Table 3.2.2.2. Activity-ratios on fresh weight basis, Mytilus edulis soft part (from Table 3.2.2.1.) to Brown algae (from Table 3.2.1.2.) collected at Ringhals May 1978

Location	^{137}Cs	^{58}Co	^{60}Co	^{54}Mn	^{65}Zn	^{110m}Ag	$^{239,240}Pu$
7	0.44	0.19	0.19	0.06	0.35	0.52	0.32
5	0.53	0.27	0.17		0.36		0.66
8	0.51	0.39	0.32		0.48		0.22

Based on the results from table 3.2.2.1, the annual dose to a hypothetically critical individual consuming 20 kg of Mytilus

edulis soft parts sampled at Ringhals would be < 0.1 mrem y^{-1}, i.e. less than 1 o/oo of the background radiation dose.

Approximately half of this dose comes from ^{137}Cs, which originates predominantly from fallout and releases from Windscale.

3.2.3. γ-emitting radionuclides in fish

Table 3.2.3.1 shows the concentrations of gamma-emitting radionuclides in fish meat from Barsebäck and Ringhals 1978. Traces of corrosion products were detected.

Table 3.2.3.1. Gamma-emitting radionuclides in fish meat collected at Barsebäck and Ringhals in 1978. (Unit: pCi kg^{-1} fresh weight)

Location		Date	Species	^{137}Cs	^{65}Zn	^{134}Cs	^{60}Co
Barsebäck	36	18/4	Plaice	49			
"	"	"	Cod	112			
"	"	"	Flounder	67			
"	"	"	Dab	55			
Ringhals	14	21/5	Red Sole	47	24 B		
"	"	"	Dab	60		4.8 A	
"	"	"	Plaice	25			3.2 A
"	"	"	Cod	80	28 B		5.3 A
"	"	"	Sole	36			

3.2.4. γ-emitting radionuclides in sea-sediments

Sediments were as previously sampled by the HAPS bottom corer[18] and 3-cm thick sections were analyzed (tables 3.2.4.1 and 3.2.4.2).

^{60}Co is now detectable in most samples near the power plants. The ratio $^{60}Co/^{137}Cs$ shows that the newer ^{60}Co has not penetrated as deeply as the older fallout nuclide ^{137}Cs.

Table 3.2.4.1. Gamma-emitting radionuclides in sediment samples collected at Barsebäck in 1978

Position	Date	Depth in cm	^{137}Cs		^{60}Co		^{54}Mn	
			pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}
17	18/4	0-3	990	6.9	529	3.7		
"	"	3-6	560	8.4				
"	"	6-9	159	2.8				
		0-9		Σ 18.1		Σ 3.7		
18	18/4	0-3	1030	11.8	509	5.8	56 A	0.6 A
"	"	3-6	734	8.4	39	0.44		
"	"	6-9	254	2.8				
"	"	9-12	96	1.23				
"	"	12-15	52	0.74				
"	"	15-18	51 A	0.68 A				
"	"	18-22	30 A	0.65 A				
		0-22		Σ 26.3		Σ 6.2		Σ 0.6
19	18/4	0-3	804	5.1	538	3.4		
"	"	3-6	418	4.2	116	1.2		
"	"	6-9	186	1.97	15 A	0.2 A		
"	"	9-12	92	1.14				
"	"	12-15	76	0.85				
		0-15		Σ 13.3		Σ 4.8		
17	17/6	0-3	976	10.4	298	3.2	102 B	1.1 B
"	"	3-6	661	8.7			86 B	1.1 B
		0-6		Σ 19.1		Σ 3.2		Σ 2.2
18	17/6	0-3	1210	11.0	1010	9.1		
"	"	3-6	984	10.5	108	1.1	47 A	0.5 A
"	"	6-9	594	7.3				
"	"	9-12	210	2.7				
"	"	12-15	93	1.24				
"	"	15-18	45	0.70				
"	"	18-21	28	0.47				
		0-21		Σ 33.9		Σ 10.2		Σ 0.5
19	17/6	0-3	382	7.7	144	2.9		
"	"	3-6	328	5.4				
		0-6		Σ 13.1		Σ 2.9		
31	17/6	0-3	1010	12.2	336	4.0		
"	"	3-6	417	6.3				
"	"	6-9	B.D.L.	B.D.L.				
"	"	9-12	B.D.L.	B.D.L.				
"	"	12-15	B.D.L.	B.D.L.				
"	"	15-18	B.D.L.	B.D.L.				
		0-18		Σ 18.5		Σ 4.0		

Table 3.2.4.1. (continued)

18	22/9	0-3	1070	12.0	720	8.1	57 B	0.6 B
"	"	3-6	520	6.2	24 A	0.3 A	27 B	0.3 B
"	"	6-9	113	1.4				
		0-9		Σ 19.6		Σ 8.4		
19	22/9	0-3	930	7.0	609	4.6		
"	"	3-6	540	6.0	107	1.2		
"	"	6-9	410	4.4				
		0-9		Σ 17.4		Σ 5.8		
38	7/12	0-3	1260	11.7	316	2.9		
"	"	3-6	700	7.5				
"	"	6-9	240	2.8				
		0-9		Σ 22.0		Σ 2.9		
39	7/12	0-3	660	13.7	200	4.3		
"	"	3-6	224	5.5				
"	"	6-9	52 B	1.6 B				
		0-9		Σ 20.8		Σ 4.3		
40	7/12	0-3	855	14.6	176	3.0		
"	"	3-6	239	4.7				
"	"	6-9	56 A	1.3 A				
		0-9		Σ 20.6		Σ 3.0		
41	7/12	0-3	1230	10.2	470	3.9		
"	"	3-6	518	5.9				
"	"	6-9	116 A	1.4 A				
		0-9		Σ 17.5		Σ 3.9		
42	7/12	0-3	1070	13.5	1610	20.4		
"	"	3-6	706	10.2				
"	"	6-9	160 A	2.7 A				
		0-9		Σ 26.4		Σ 20.4		
43	7/12	0-3	1210	16.4	516	7.0		
"	"	3-6	650	8.8				
"	"	6-9	246	3.5				
		0-9		Σ 28.7		Σ 7.8		
[illegible]	7/12	0-3	1038	12.2	205	2.4		
"	"	3-6	790	9.3				
"	"	6-9	215 A	3.6 A				
		0-9		Σ 24.5		Σ 2.4		
45	7/12	0-3	960	10.3	210 A	2.3 A		
"	"	3-6	392	5.3				
"	"	6-9	116 A	1.7 A				
		0-9		Σ 17.3		Σ 2.3		

Table 3.2.6.2. Gamma-emitting radionuclides in sediment samples collected at Bisphala in 1978

Position	Date	Depth in cm	^{137}Cs		^{60}Co		^{54}Mn		^{65}Zn	
			pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}
1	21/5	0-3	360	6.6						
"	"	3-6	206	7.2						
"	"	6-9	107	3.4						
"	"	9-12	46 A	1.6 A						
"	"	12-15	28 B	1.1 B						
		0-15		Σ 19.7						
2	21/5	0-3	347	9.0	200	5.2			440 A	11.6 A
"	"	3-6	264	8.6						
		0-6		Σ 17.6		Σ 5.2				Σ 11.6
3	21/5	0-3	183	4.2	192	4.5	70 A	1.6 A		
"	"	3-6	108	3.3	50	1.5			200	6.7
"	"	6-9	62	1.7						
"	"	9-12	30 A	1.3 A	37 A	1.2 A				
"	"	12-15	93 A	1.5 A						
		0-15		Σ 12.0		Σ 7.2		Σ 1.6		Σ 6.7
4	21/5	0-3	71	2.9	80	3.5				
"	"	3-6	85	3.3	51	2.0				
		0-6		Σ 6.2		Σ 5.5				
1	4/9	0-3	149	4.7						
"	"	3-6	54 B	2.1 B						
"	"	6-9	38 B	1.4 B						
"	"	9-12	B.D.L.	B.D.L.						
		0-12		Σ 8.2						
2	4/9	0-3	297	7.4	301	7.6	41 B	1.0 B		
"	"	3-6	167	5.6	63	2.1				
"	"	6-9	165	6.2	12 B	0.4 B				
"	"	9-12	86	3.1						
		0-12		Σ 22.3		Σ 10.1		Σ 1.0		
3	4/9	0-3	190	5.9	261	8.1				
"	"	3-6	111	4.3	85	3.3				
"	"	6-9	29	1.2						
"	"	9-13	26 A	1.6 A						
		0-13		Σ 13.0		Σ 11.4				
4	4/9	0-3	123	4.2	187	6.4				
"	"	3-6	77	3.2	110	4.6	16 B	0.7 B		
"	"	6-9	55	2.4	24	1.0				
"	"	9-12	34	1.4						
		0-12		Σ 11.2		Σ 12.0				

The Barsebäck results have been used to estimate the total ^{60}Co content of sediments within 20 km from the power plant. On the assumptions that 1) the ^{60}Co contents out to a distance of 4 km is represented by the geometric mean of all 17 samples, i.e. 4.66 mCi km^{-2} (S.D. factor 1.78), 2) the ^{60}Co concentration from 4 to 20 km declines at the same rate as found for Fucus along the Swedish coastline, i.e. $A = k\ X^{-1.4}$ where X is the distance in km, and 3) only 180^{o} of the circle around Barsebäck is water covered; this estimation is in the range 100-400 mCi ^{60}Co. From the start in 1975 till the end of 1978 a total discharge of 2574 mCi ^{60}Co (not decay-corrected) was reported[35].

4. FALLOUT NUCLIDES IN THE ABIOTIC ENVIRONMENT

by A. Aarkrog and J. Lippert

4.1. Air

4.1.1. Strontium-90

The mean air activity level for 1978: 1.12 fCi $^{90}Sr\ m^{-3}$, i.e. 1.6 times the 1977 level. The maximum activity in 1978 was measured in May at 3.25 fCi $^{90}Sr\ m^{-3}$.

Figure 4.1.1 shows the quarterly levels of ^{90}Sr in air since 1957.

Table 4.1.1. Strontium-90 in air collected at Risø in 1978

Month	fCi $^{90}Sr\ m^{-3}$
Jan	0.75
Feb	0.86
March	1.54
April	1.57
May	3.26
June	2.16
July	1.04
Aug	0.88
Sept	0.38
Oct	0.43
Nov	0.29
Dec	0.33
1978	1.12

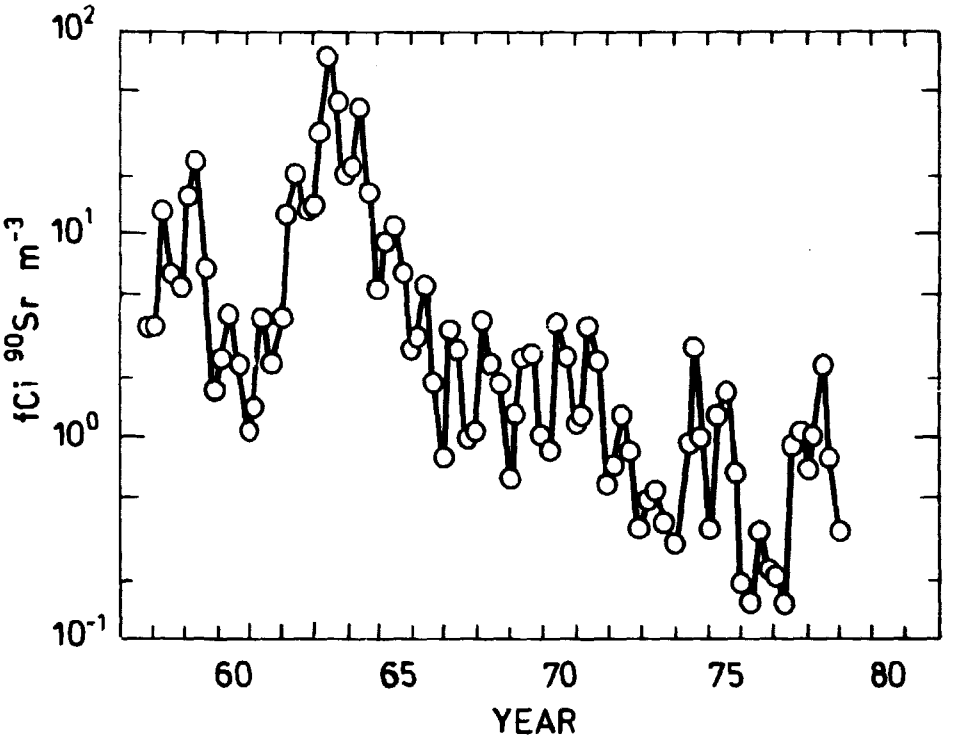

Fig. 4.1.1. Quarterly ^{90}Sr levels in air, 1957-1978.

4.1.2. Cesium-137

As in 1962-1977, samples of air were collected twice a week by means of the air sampler described in Risø Report No. 23[1]. The filters were measured on a 100 cm^3 Ge(Li) detector[8]. Table 4.1.2 shows the monthly means of the ^{137}Cs determinations (cf. also fig. 4.1.2). The peak value was observed in May. The mean level in 1978 was 1.94 times the 1977 mean. The ^{137}Cs/^{90}Sr mean ratio in the air filter was 2.8 in 1978, which is a remarkable high ratio.

The increase in the ^{137}Cs and ^{90}Sr levels in air in 1978 resulted from the global fallout originating from the 4 Mt Chinese test explosion on November 17, 1976, which contrary to previous experience first showed its maximum in the second year after the explosion.

Table 4.1.2. Cesium-137 in glass-fibre air filters collected twice a week at Risø in 1978

Month	fCi ^{137}Cs m^{-3}
Jan	2.10±0.22
Feb	2.34±0.25
March	4.13±0.81
April	4.56±0.38
May	9.10±0.97
June	5.36±0.97
July	3.06±0.27
Aug	2.29±0.65
Sept	1.09±0.10
Oct	2.07±1.09
Nov	0.72±0.09
Dec	0.87±0.08
1978	3.14

The error term is the S.E. of the mean of the activity found in 8 or 9 filters collected during a month.

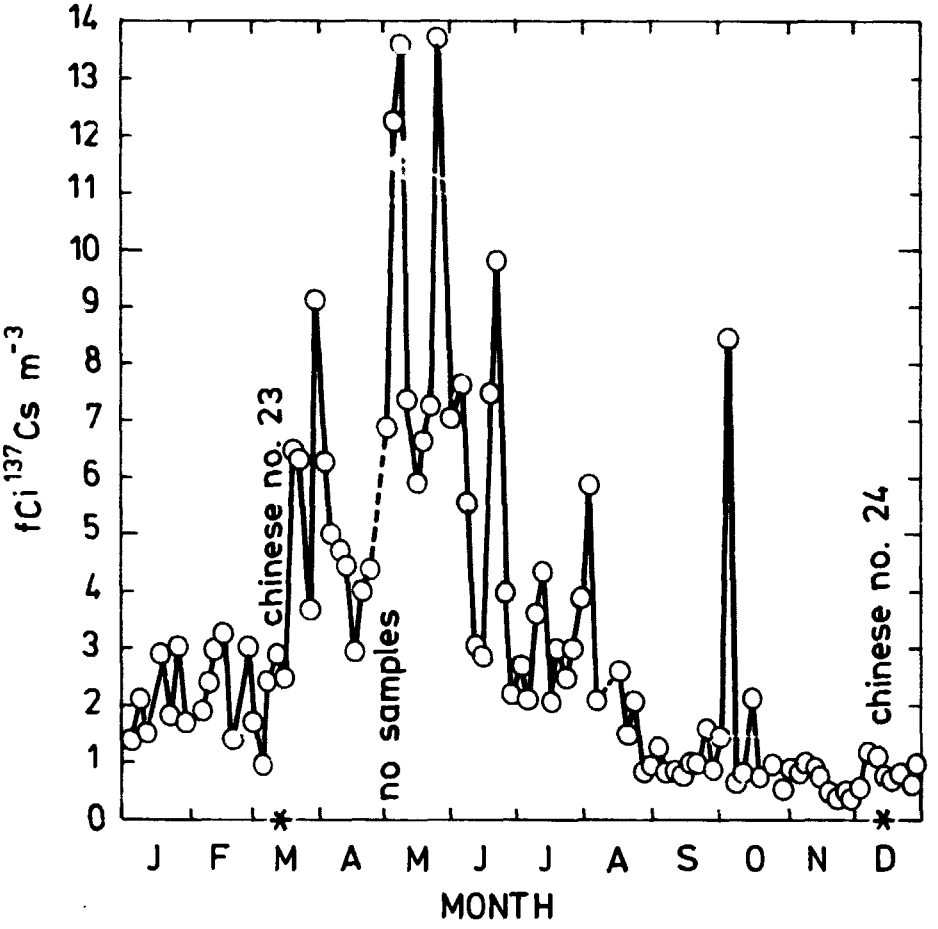

Fig. 4.1.2. Cesium-137 in ground level air at Risø in 1978.

4.1.3. Short-lived γ-emitting nuclides in air and precipitation

On March 14, 1978, China tested a nuclear weapon in the kilotons range in the atmosphere. As shown in fig. 4.1.3, fresh fallout appeared in ground-level air approximately 11 days later, and the peak activities occurred on April 3, i.e., 20 days after the explosion.

Table 4.1.3 shows the washout ratios, W_o based on the measurements of short-lived γ-emitters in air and rain samples collected at Risø in March-April 1978. The overall mean of W_o for all nuclides was 0.65.

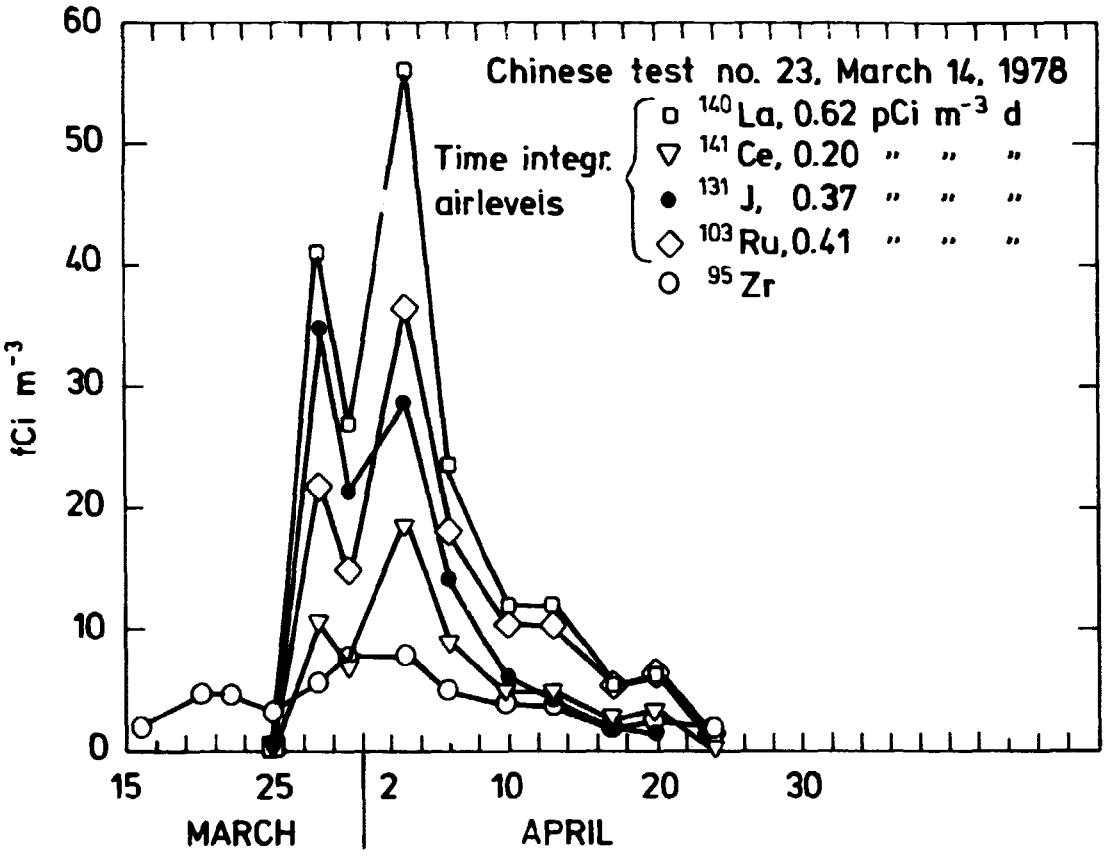

Fig. 4.1.3. Short lived fissions products in airborne debris from the Chineese test explosion 14 March 1978 collected in groundlevel air at Risø, March-April 1978. The time-integrated levels are indicated for the various radionuclides.

Table 4.1.3. Washout factors (W_o) in fresh debris collected in 1978.

$$W_o = \frac{\text{pCi } l^{-1} \text{ rain}}{\text{fCi } m^{-3} \text{ air}}$$

Precipitation periods	^{140}La	^{141}Ce	^{95}Zr	^{131}I	^{103}Ru
25/3-31/3	0.70	0.55	0.43	1.32	0.89
1/4-30/4	0.58	0.40	0.67	0.35	0.62

The time-integrated air levels of the short-lived fallout nuclides in 1978 were generally lower than the corresponding values observed in the autumn of 1977, which originated from the Chinese nuclear test on September 17, 1977 (cf. fig. 4.1.3 and Risø Report No. 386[1]).

4.2. Strontium-90 in precipitation

Samples of rain water were collected in 1978 from the State experimental farms (cf. fig. 4.2) in accordance with the principles laid down in Risø Report No. 63, p. 51[1].

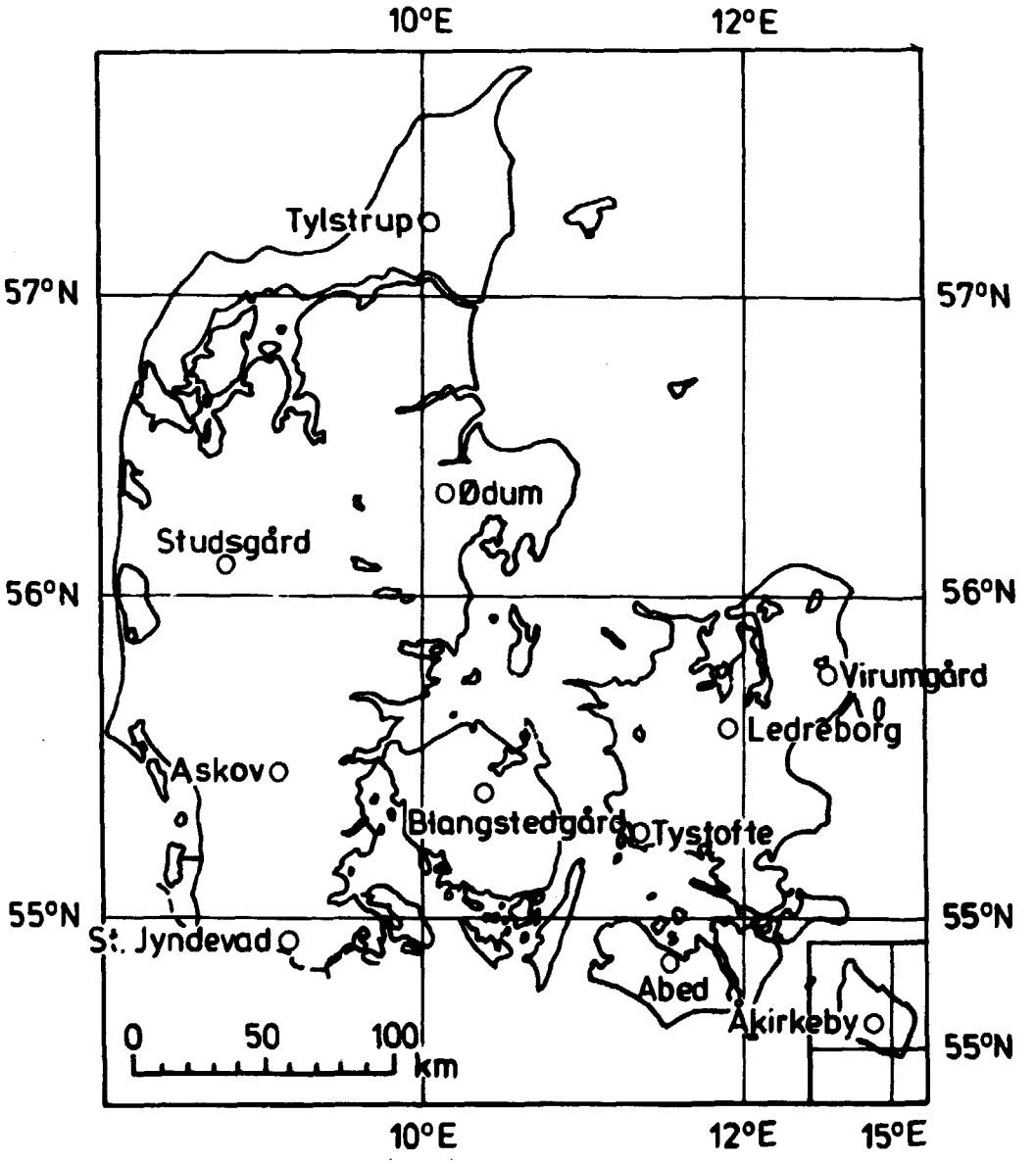

Fig. 4.2. State experimental farms in Denmark.

Table 4.2.1 shows the results of the ^{90}Sr determinations and tables 4.2.2 and 4.2.3 the analysis of variance of the results.

Table 4.2.1. Strontium-90 fall-out in Denmark in 1978

Period	Unit		Tylstrup	Studs-gård	Ødum	Askov	St. Jyndevad	Blangstedgård	Tystofte	Abed	Åkirkeby	Ledreborg	Mean
Jan-Feb	pCi l^{-1}		0.98	0.98	0.88	0.67	0.60	0.71	0.78	1.22	0.90	0.68	0.80
	mCi km^{-2}		0.054	0.069	0.044	0.064	0.067	0.076	0.057	0.065	0.042	0.037	0.058
March-April	pCi l^{-1}		0.86	1.12	1.05	1.03	1.33	0.90	1.71	1.34	1.35	1.18	1.18
	mCi km^{-2}		0.070	0.157	0.082	0.136	0.186	0.101	0.119	0.094	0.082	0.059	0.109
May-June	pCi l^{-1}		2.32	6.40	2.88	1.26	2.30	1.89	1.31	4.32	8.77	1.87	2.27
	mCi km^{-2}		0.185	0.158	0.142	0.201	0.197	0.072	0.090	0.126	0.091	0.095	0.136
July-Aug	pCi l^{-1}		0.72	0.91	1.13	0.97	0.97	1.22	1.54	0.82	0.69	0.70	0.90
	mCi km^{-2}		0.106	0.095	0.049	0.103	0.136	0.067	0.139	0.084	0.117	0.060	0.096
Sept-Oct	pCi l^{-1}		0.34	0.32	0.35	0.30	0.35	0.24	0.116 B	0.24	0.78	0.33	0.33
	mCi km^{-2}		0.052	0.063	0.043	0.048	0.067	0.030	0.011 B	0.035	0.070	0.046	0.047
Nov-Dec	pCi l^{-1}		0.26	0.25	0.21	0.21	0.179	0.28	0.065 A	0.22	0.30	0.189	0.22
	mCi km^{-2}		0.024	0.028	0.012	0.029	0.022	0.025	0.005 A	0.017	0.017	0.009	0.019
1978	pCi l^{-1}	$\bar{x}$	0.80	0.88	0.93	0.73	0.85	0.70	0.89	0.86	0.99	0.72	0.83
	mCi km^{-2}	Σ	0.491	0.570	0.372	0.581	0.675	0.371	0.421	0.421	0.419	0.306	0.463
mm precipitation Σ			608	648	400	792	792	526	474	490	424	428	558

Table 4.2.2. Analysis of variance of ln pCi $^{90}Sr\ l^{-1}$ precipitation in 1978 (from Table 4.2.1)

Variation	SSD	f	s^2	v^2	P
Between months	44.353	5	8.871	61.055	>99.95%
Between locations	2.369	9	0.263	1.812	-
Remainder	6.538	45	0.145		

Table 4.2.3. Analysis of variance of ln pCi $^{90}Sr\ km^{-2}$ precipitation in 1978 (from Table 4.2.1)

Variation	SSD	f	s^2	v^2	P
Between months	28.148	5	5.630	44.892	>99.95%
Between locations	4.067	9	0.452	3.603	>99.5%
Remainder	5.643	45	0.125		

The maximum concentration in precipitation occurred in May-June, when the mean content in precipitation was 2.27 pCi $^{90}Sr\ l^{-1}$ (cf. also the air measurements in 4.1.1), and the maximum fallout rate also occurred in May-June, 0.136 mCi $^{90}Sr\ km^{-2}$. The mean levels for ten State experimental farms were 0.46 mCi $^{90}Sr\ km^{-2}$ and 0.83 pCi $^{90}Sr\ l^{-1}$. The fallout rate in 1978 was 1.2 times that observed in 1977. The ^{90}Sr deposition in 1978 was 1.4 times higher in Jutland than in the Islands.

A comparison between the amounts of precipitation found in the rain gauges used by the Danish Meteorological Institute[9] and the amounts collected in our rain bottles at the same locations in 1978 showed a mean ratio of 1.38 $\pm$ 0.06 (1 SE) between the two sampling systems. The difference between the two systems resulted mainly from evaporation taking place in the Risø rain bottles during the sampling period.

Table 4.2.4 shows the quarterly ^{90}Sr levels in precipitation samples collected in ion-exchange columns at Risø in 1977. The total deposition was 0.27 mCi $^{90}Sr\ km^{-2}$ and the mean concen-

tration was 0.56 pCi ^{90}Sr l^{-1}. These figures were compatible with those in table 4.2.1 for Ledreborg, the nearest precipitation station to Risø.

Table 4.2.4. Strontium-90 in rain water collected in ion-exchange column collectors at Risø in 1978 (sampling area 0.325 m^2)

Month	mm	pCi ^{90}Sr l^{-1}	mCi ^{90}Sr km^{-2}
Jan-March	102	0.60	0.062
April-June	65	1.33	0.087
July-Sept	229	0.42	0.096
Oct-Dec	80	0.29	0.023
1978	Σ 476	$\bar{x}$ 0.56	Σ 0.268

Table 4.2.5 shows the ^{137}Cs levels in rain water collected at a new 9 m^2 rain collector (cf. fig. 4.2.5). The ^{137}Cs concentrations in the rain was lower than expected from the ^{90}Sr precipitation levels (4.2.1) and from the $^{137}Cs/^{90}Sr$ air ratio (4.1.2). The efficiency of the ionexchange column may need further investigations.

Table 4.2.5. Cesium-137 in rain water collected in a big ion-exchange column collector at Risø in 1978 (sampling area 9 m^2)

Period	mm	pCi ^{137}Cs l^{-1}	mCi ^{137}Cs km^{-2}
11/1-3/2	55	0.83	0.046
3/2-16/3	47	1.17	0.055
16/3-30/3	31	0.74	0.023
April	12	2.30	0.028
May	11	2.10	0.023
June	30	1.25	0.038
July	73	0.72	0.053
August	66	0.39	0.026
September	139	0.41	0.057
October	47	0.39	0.0183
November	31	0.55	0.0170
December	37	0.41	0.0152
1978	Σ 579	$\bar{x}$ 0.69	Σ 0.400

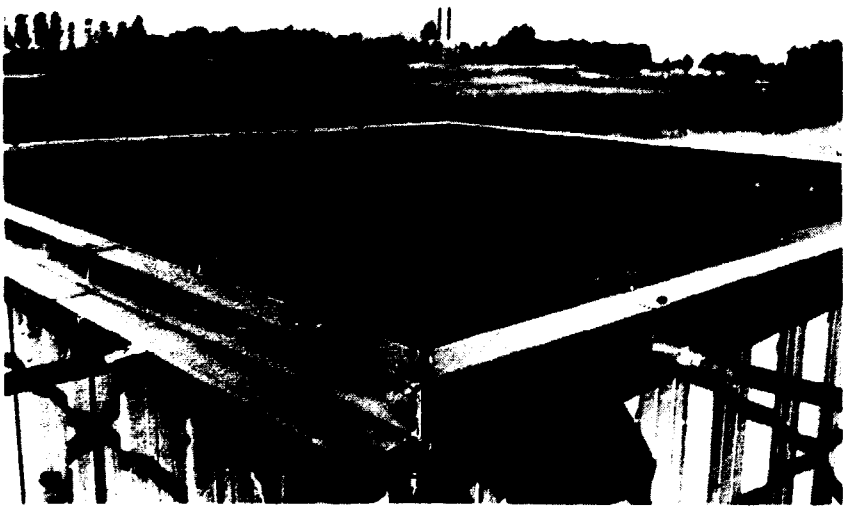

Fig. 4.2.5. Large raincollecter provided with ion-exchange column installed in a frost proof room.

4.3. Fresh water

4.3.1. Strontium-90 in ground water

As in previous years[1)], ground water was collected in March from the nine locations selected by the Geological Survey of Denmark. Figure 4.3.1.1 shows the sample locations and table 4.3.1 the results of the ^{90}Sr analyses.

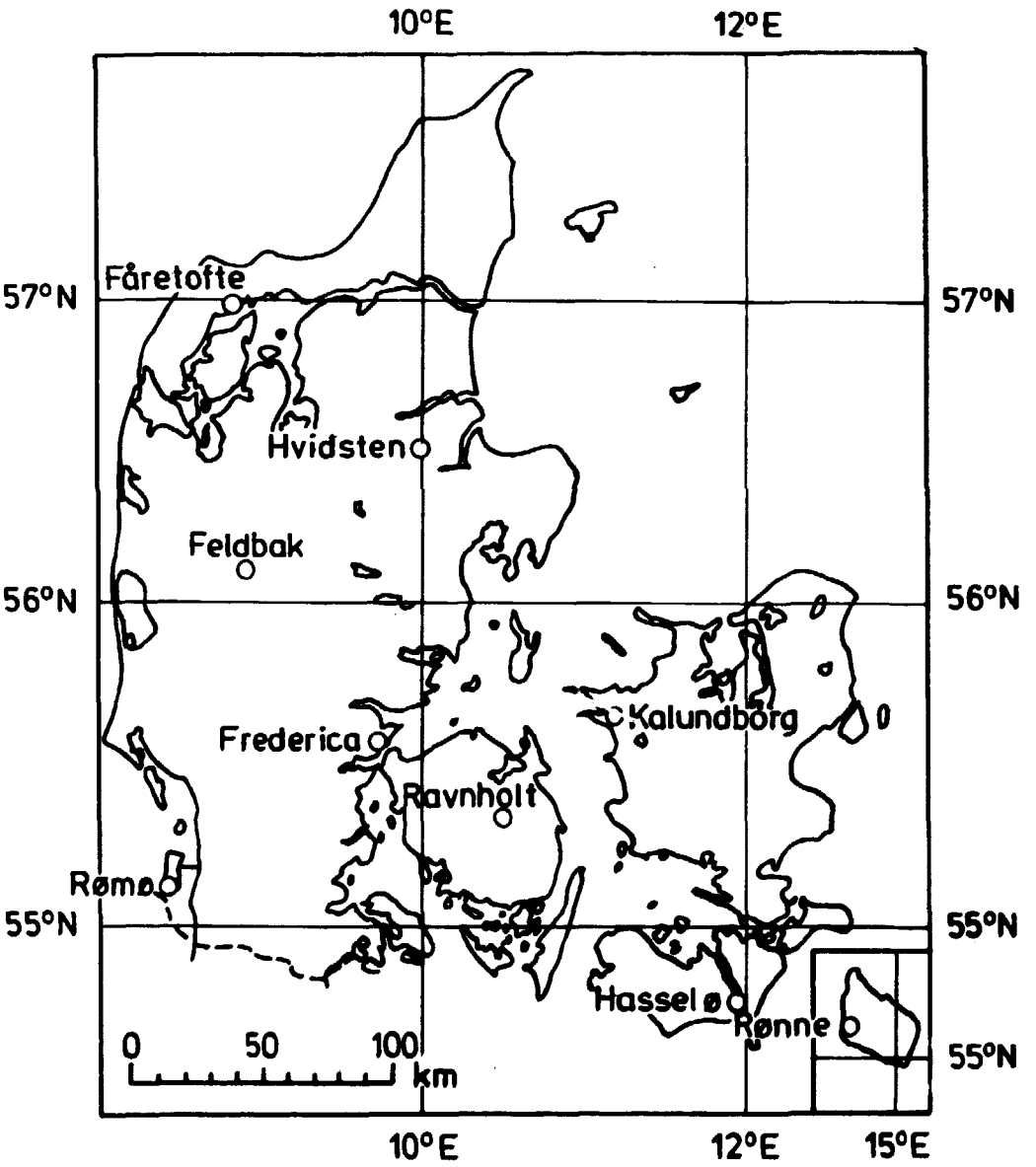

Fig. 4.3.1.1. Ground water sampling locations in Denmark.

Table 4.3.1. Strontium-90 in ground water collected in March 1978

Location	fCi $^{90}Sr\ l^{-1}$	g Ca l^{-1}
Hvidsten	2.5 B	0.0766
Feldbak	2788	0.0357
Rønø	1.3 A	0.0418
Rønne New	14.7	0.0042
Rønne Old	10.5	0.0321
Hasselø	3.3 B	0.122
Fåretofte	3.7	0.144
Kalundborg	21.0	0.0969
Ravnholt	13.6	0.0942
Fredericia	14.8	0.0889
Mean	287	0.0736
Median	12	0.0828

A sample of ground water from Maglekilde in Roskilde contained 6.5 fCi $^{90}Sr\ l^{-1}$ and 0.1313 g Ca l^{-1}.

The median level of ^{90}Sr in 1978 was compatible with the values found since 1967 (cf. fig. 4.3.1.2).

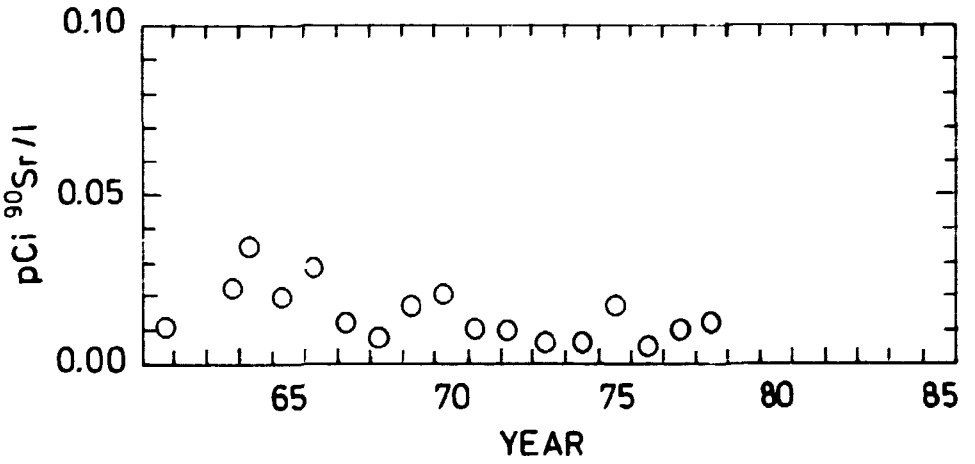

Fig. 4.3.1.2. Median ^{90}Sr levels in Danish ground water, 1961-1978.

As appears from fig. 4.3.1.3, the ^{90}Sr levels in ground water from Feldbak have been around 1.5-2 pCi l^{-1} in later years. ^{137}Cs was not measurable in 45 l samples of Feldbak water from 1977, 1978 and 1979; the levels must have been less than 0.2 pCi ^{137}Cs l^{-1}.

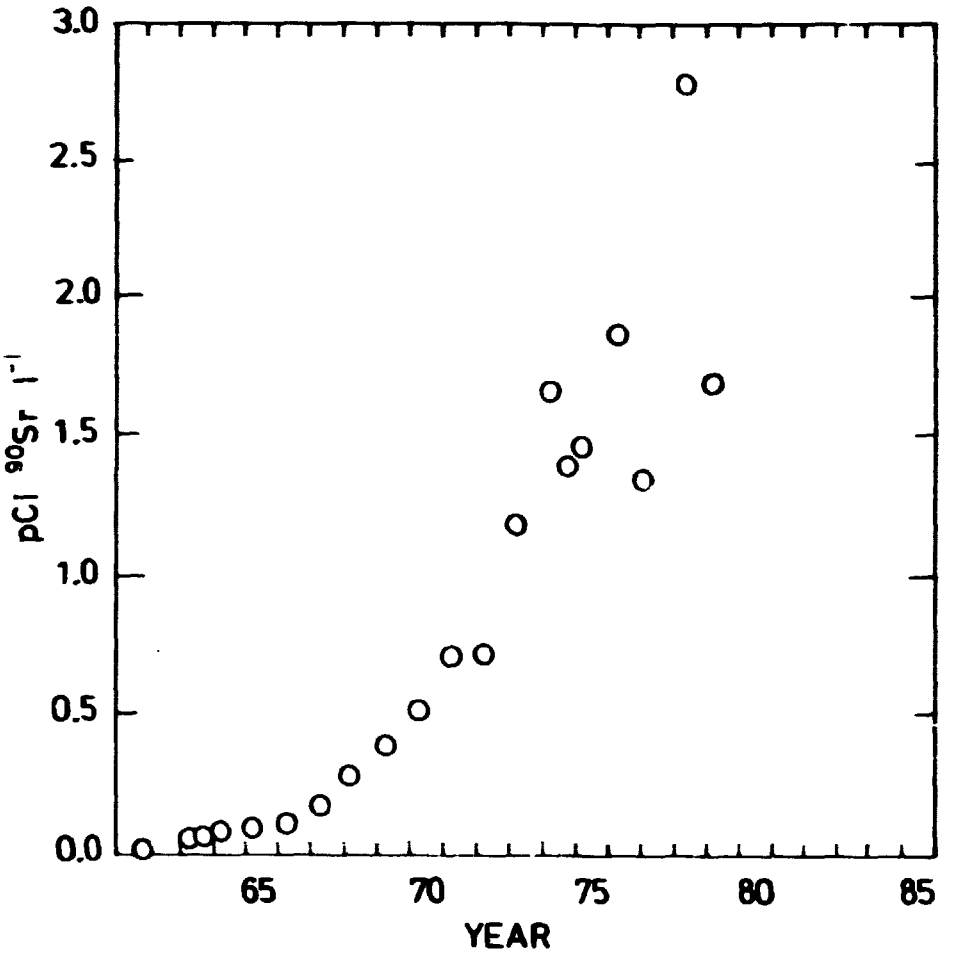

Fig. 4.3.1.3. Strontium-90 in ground water at Feldbak 1961-1979.

4.3.2. Cesium-137 in fresh water from Danish streams

In October 1978 we collected fresh water from three large Danish streams in order to determine ^{137}Cs.

Table 4.3.2. Cesium-137 in fresh water from Danish streams collected in October 1978

Zone			pCi ^{137}Cs l^{-1}
II:	East Jutland	Guden å	0.05
III:	West Jutland	Skjern å	0.03 A
VI:	Zealand	Susså	0.04 A

The results are shown in table 4.3.2. It appears that the ^{137}Cs concentrations were in the order of 10-20% of the corresponding ^{90}Sr concentrations measured in 1977 (Risø Report No. 386[1], table 4.3.2), which is in agreement with the observations in other countries.

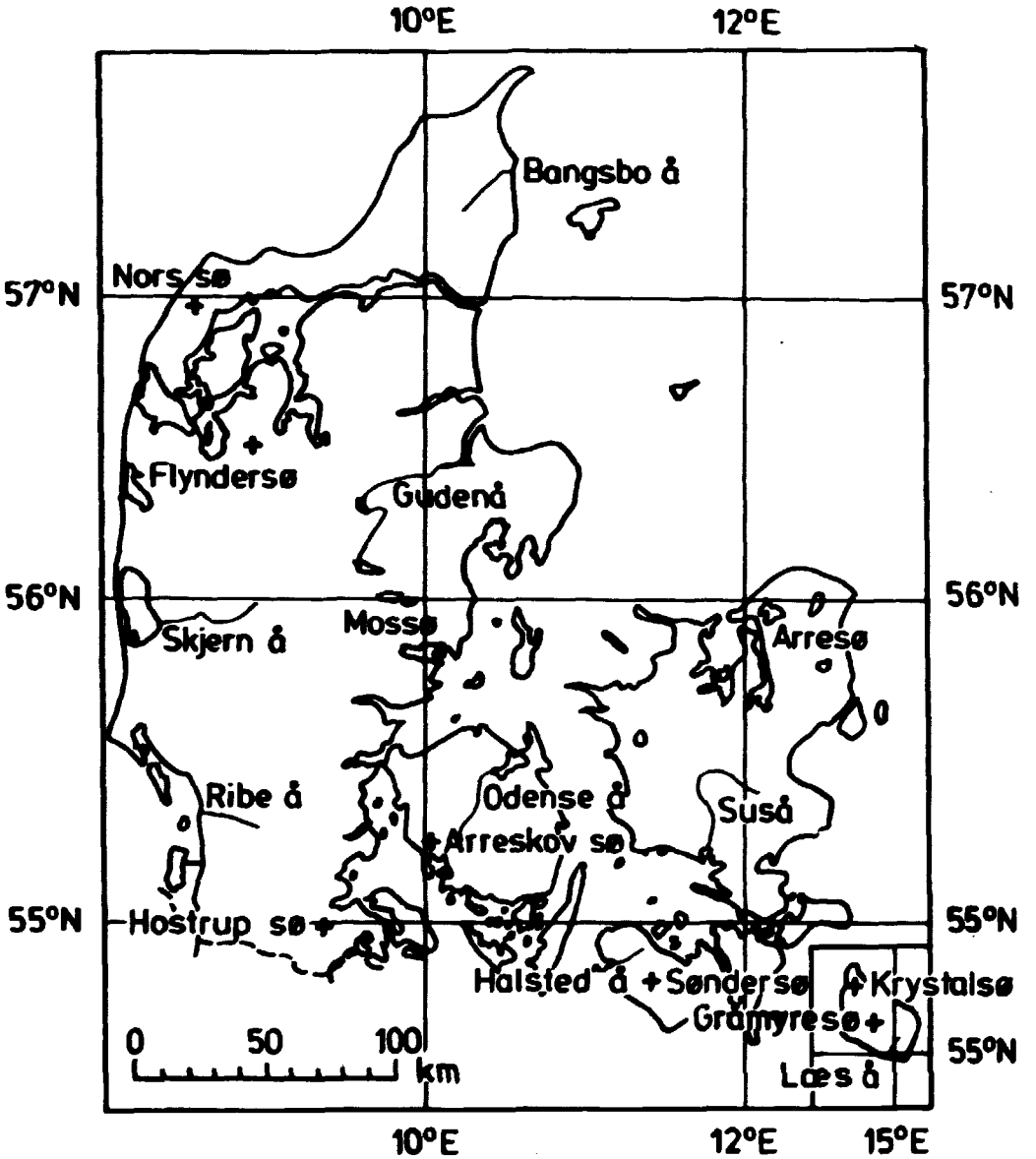

Fig. 4.3.2. Sample locations for fresh water from Danish streams and lakes.

4.4. Strontium-90, Cesium-137 and Cesium-134 in sea water in 1978

As in previous years, sea water samples were collected by M/S Fyrholm in the summer and late autumn from inner Danish waters (cf. table 4.4.1 and figs. 4.4.1 and 4.4.2). Furthermore, sea water samples were collected at Barsebäck in the Sound (table

Table 4.4.1. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in June and December 1978

	Position		June					December				
	N	E	Depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo	Depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo
Kullen	56°15'	12°25'	0	0.81	0.99	0	16.6	0		0.71	0.03 B	13.1
"			21	0.77	2.34	0.17	35.7	21		1.98	0.15	29.2
Hesselø	56°10'	11°47'	0		1.02	0.06 B	20.7	0	0.42	1.82	0.16	29.1
"			22		1.98	0.14	33.5	25		2.27	0.16	31.9
Kattegat SW	56°07'	11°10'	0	0.68	0.97	0	16.7	0	0.59	1.59	0.12	26.5
"			35		1.80	0.12 A	35.6	40		2.50	0.15	32.1
Asnæs rev	55°38'	10°47'	0		0.70	0	13.2	0	0.56	1.73	0.11	25.7
" "			40	0.68	1.80	0.12	34.2	45		2.42	0.15	31.9
Halskov rev	55°20'	11°02'	0	0.70	0.68	0	12.8	0	0.67	1.52	0.10	34.2
" "			34		1.81	0.16	34.2	40	0.64	1.75	0.08	27.3
Langeland bælt	54°52'	10°50'	0		0.74	0.05 B	13.9	0	0.49	1.48	0.10	10.5
" "			47		1.72	0.09 A	33.2	45		1.54	0.10	24.7
Femern bælt	54°36'	11°05'	0	1.00	0.64	0	10.4	0	1.41	1.22	0.07 A	21.6
" "			25	0.47	1.75	0.14	30.7	21		1.32	0.06 A	22.9
Gedser rev	54°28'	12°13'	0		0.97	0	18.1	0	0.58	0.96	0.06 A	16.6
" "			23		1.32	0.09 A	24.4	26	0.36	1.01	0	19.4
Møen	54°57'	12°41'	0	0.92	0.50	0	9.0	0	0.55	0.55	0	10.4
"			20		0.90	0	18.1	25		1.41	0.07	22.9
The Sound - South	55°25'	12°39'	0		0.54	0	9.0	0		0.58	0	11.7
" " "			12		1.18	0.05 B	20.1	13		1.44	0.11	20.9
The Sound - North A	55°48'	12°44'	0	0.66	0.54	0	9.0	0	0.62	0.59	0	10.4
" " "			19		1.50	0.09 A	25.7	19		0.66	0	11.8
The Sound - North B	55°59'	12°42'	0		0.61	0	9.0	0	0.75	0.67	0	11.7
" " "			24		2.03	0.15	34.0	26		1.52	0.08	24.9
Mean			Surface	0.80	0.74	0.01	13.2		0.66	1.12	0.06	18.5
SD				0.14	0.19	0.02	4.1		0.28	0.49	0.06	8.6
SE				0.06	0.06	0.01	1.2		0.09	0.14	0.02	2.5
Mean			Bottom	0.64	1.68	0.11	30.0		0.50	1.65	0.09	25.0
SD				0.15	0.40	0.05	6.2		0.20	0.56	0.06	6.0
SE				0.09	0.11	0.01	1.8		0.14	0.16	0.02	1.7

4.4.2), and at Ringhals in the Kattegat (table 4.4.3). The DANA took samples in the North Sea (fig. 4.4.3) and the Kattegat in February (table 4.4.4).

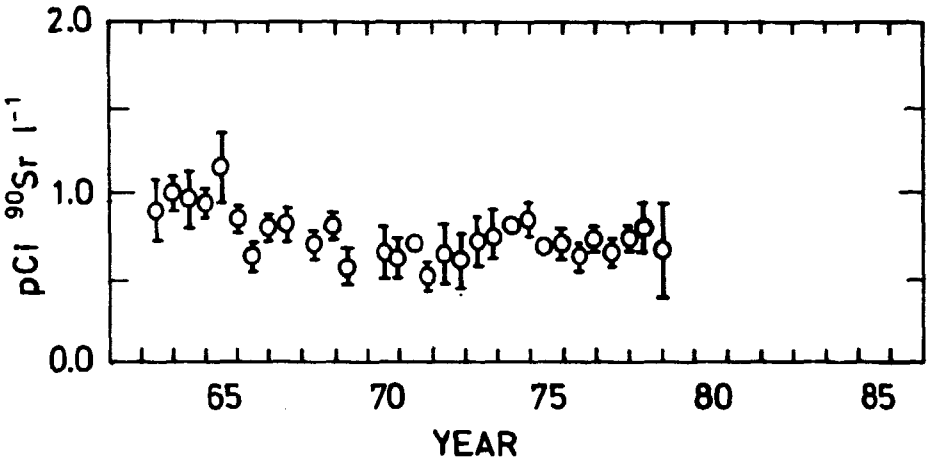

Fig. 4.4.1. Strontium-90 in surface sea water from inner Danish waters, 1962-1978 (1SD indicated) (from table 4.4.1).

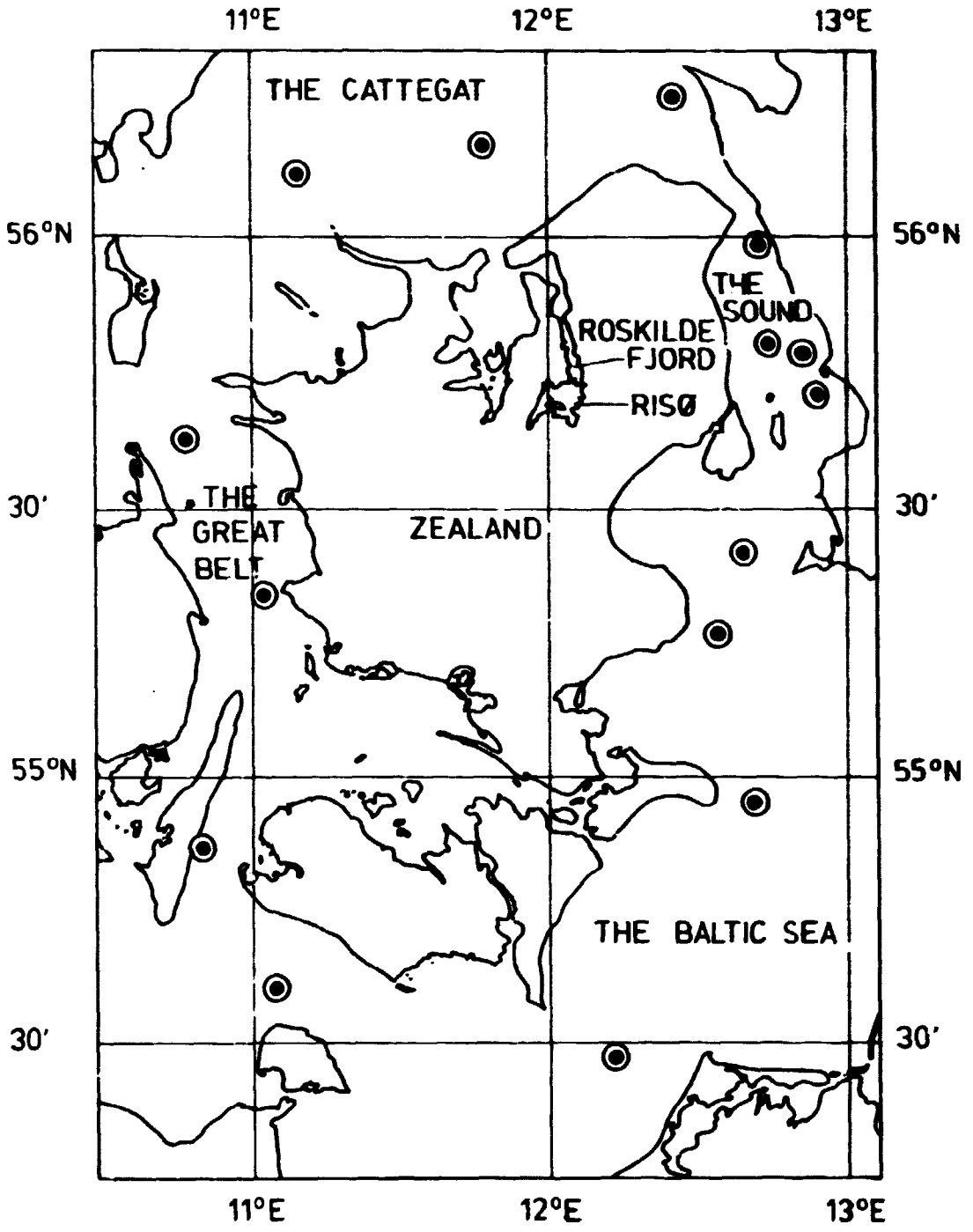

Fig. 4.4.2. Sea water locations around Zealand.

Table 4.4.2. Cesium-137 and Cesium-134 in sea water collected in the Sound (Barsebäck) in 1978
(cf. also 3.2)

Sampling location (cf. Fig. 3.2.1.)	April				June				September			
	Depth in m	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo	Depth in m	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo	Depth in m	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo
34	0	0.61	0	10.3	0	0.55	0	10.3				
"					15	1.43	0.11	25.6				
19	0	0.62±0.11	-	10.4	0	0.66±0.02	-	11.4±0.4	0	0.84	0	13.9
"					18	1.46±0.14	-	26.8	21	1.37	0.05 B	24.3
Mean	Surface	0.62		10.4	Surface	0.60	0	10.8	Surface	0.84	0	13.9
SD		0.01		0.1		0.08		0.8				
SE		0.00		.0		0.06		0.6				
Mean	Bottom				Bottom	1.44	0.11	26.2	Bottom	1.37	0.05	24.3
SD						0.02		0.8				
SE						0.02		0.6				

Table 4.4.3. Cesium-137 and Cesium-134 in sea water collected at Ringhals in 1978 (cf. also 3.2)

Sampling location (cf. Fig. 3.2.2.)	May				September			
	Depth in m	$^{137}Cs_{-1}$ pCi l^{-1}	$^{134}Cs_{-1}$ pCi l^{-1}	Salinity o/oo	Depth in m	$^{137}Cs_{-1}$ pCi l^{-1}	$^{134}Cs_{-1}$ pCi l^{-1}	Salinity o/oo
0*	0	0.91	0	16.7	0	1.59	0.08	25.8
"	66	2.67	0.20	34.2	60	2.08	0.17	34.3
1	0	1.00	0	18.1				
"	27	2.53	0.19	36.0				
2	0	1.08	0.05 B	18.0				
"	22	2.56	0.17	36.0				
3	0	1.14	0.05 A	19.5	0	2.06	0.17	32.1
"	18	1.97	0.14	32.8	17	2.19	0.14	32.1
15	0	0.97	0.08 A	19.4				
"	10	1.98	0.15	27.8				
Mean	Surface	1.02	0.04	18.3	Surface	1.82	0.12	28.9
SD		0.09	0.04	1.2		0.33	0.06	4.4
Se		0.04	0.02	0.5		0.24	0.04	3.2
Mean	Bottom	2.34	0.17	33.4	Bottom	2.14	0.16	33.2
SD		0.34	0.02	3.4		0.08	0.02	1.6
SE		0.15	0.01	1.5		0.06	0.02	1.1

*$57^{o}14'N$ $11^{o}53'7"E$

In Risø Report No. 305[1] it was suggested that the increasing ^{90}Sr and ^{137}Cs levels observed in 1973 in inner Danish waters were the result of contamination from the inflow of water from the North Sea, which was contaminated with ^{137}Cs and ^{90}Sr from nuclear plants in the UK and France.

In accordance with this hypothesis, the ^{90}Sr concentration has increased especially in sea water of high salinity, as shown in the following regression equations:

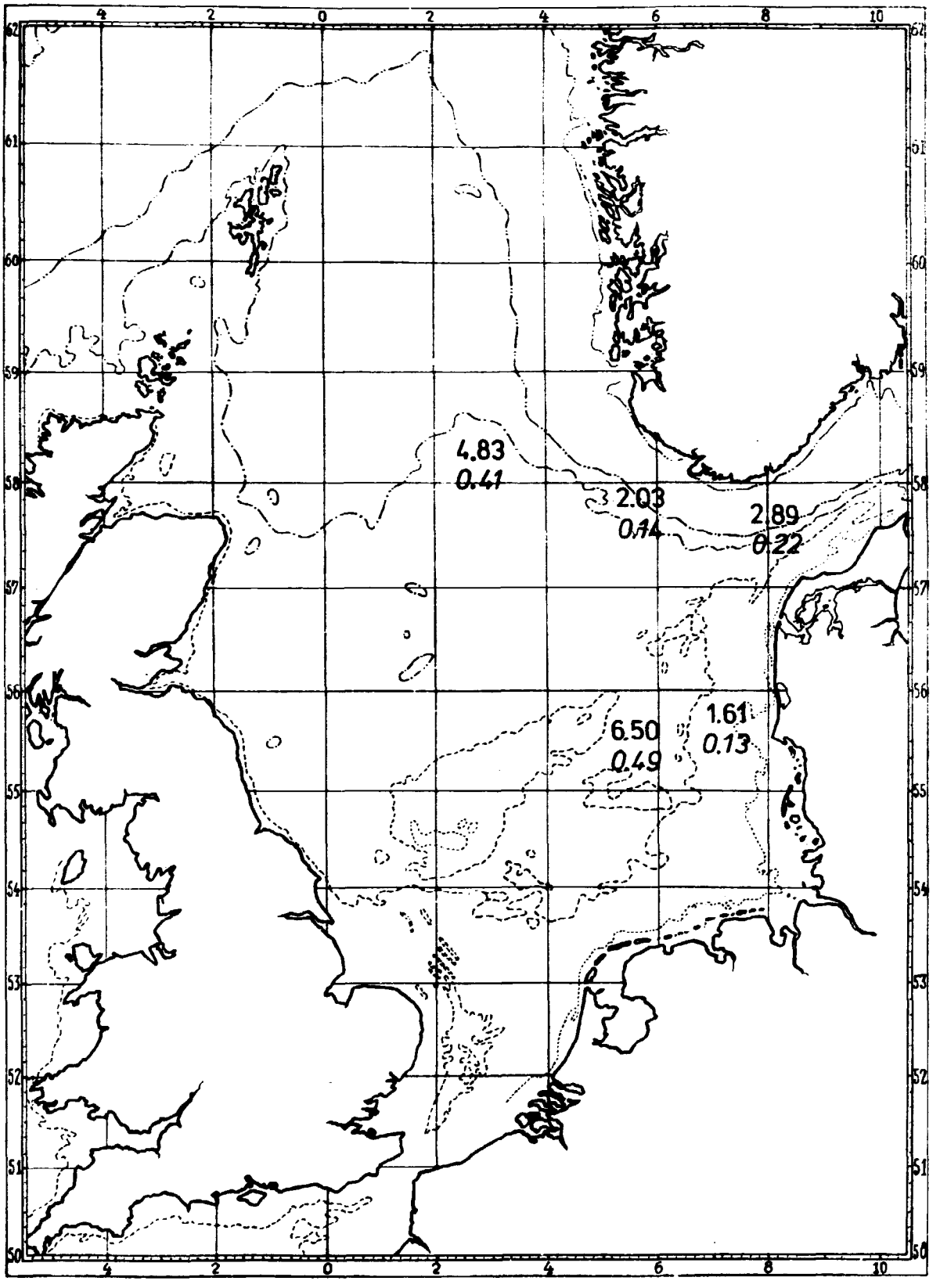

Fig. 4.4.3. Concentrations (pCi l^{-1}) of ^{137}Cs and ^{134}Cs (italics) in surface sea water collected in 1978.

Table 4.4.4. Strontium-90, Cesium-137 and Cesium-134 in surface sea water collected at the North Sea in 1978

Position	Date	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo
55°40'2N 07°05'0E	15/9		1.61	0.13	35.4
55°26'5N 05°34'0E	15/9		6.50	0.49	35.2
58°13' N 02°42' E	4/11	0.72	4.83	0.41	35.6
57°50'N 05°27' E	5/11		2.03	0.14	35.6
57°40' N 08°02' E	5/11		2.89	0.22	32.9
Mean		0.72	3.57	0.28	34.9
SD			2.05	0.16	1.2
SE			0.92	0.07	0.5

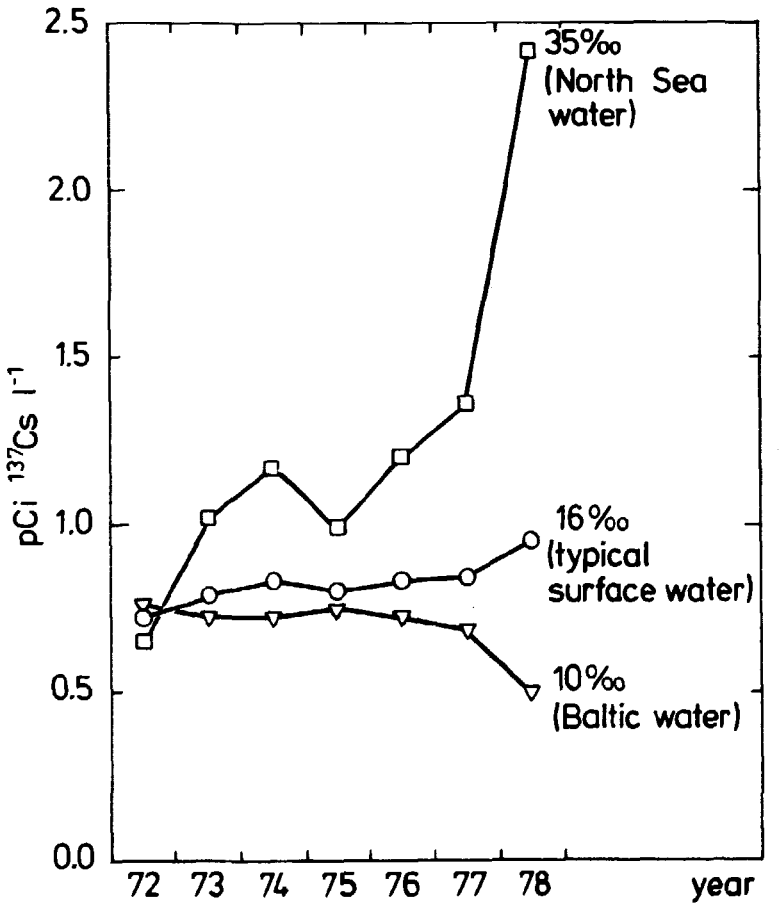

Fig. 4.4.4. Cesium-137 in inner Danish waters of 3 different salinities (1972-1978).

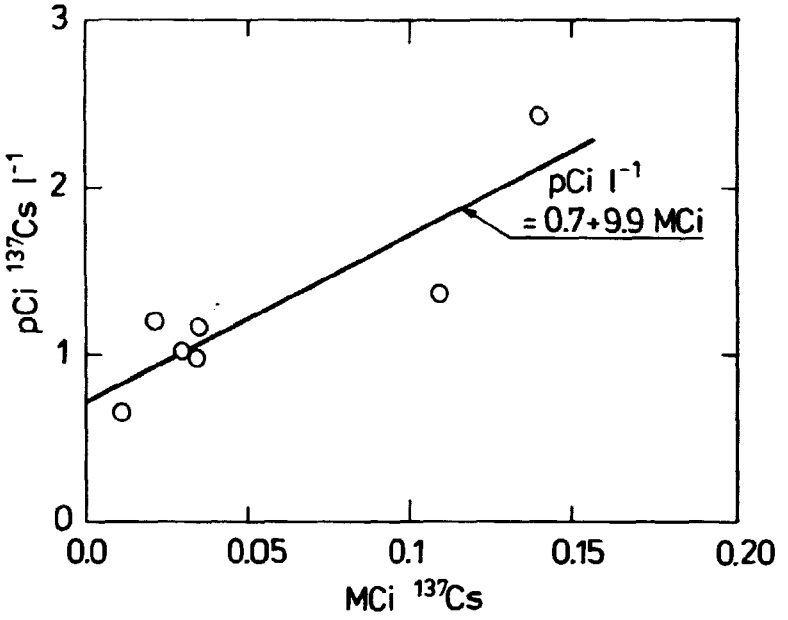

Fig. 4.4.5. Cesium-137 in Danish bottom sea water (salinity 35 o/oo) 1972-78 as a function of the releases from Windscale 3 years prior to the seawater sampling.

pCi ^{90}Sr l^{-1} = 0.94 - 0.018 o/oo (1967-1971)
pCi ^{90}Sr l^{-1} = 0.97 - 0.020 o/oo (1972)
pCi ^{90}Sr l^{-1} = 0.95 - 0.014 o/oo (1973)
pCi ^{90}Sr l^{-1} = 0.93 - 0.010 o/oo (1974)
pCi ^{90}Sr l^{-1} = 0.79 - 0.006 o/oo (1975)
pCi ^{90}Sr l^{-1} = 0.71 - 0.002 o/oo (1976)
pCi ^{90}Sr l^{-1} = 0.71 - 0.0015 o/oo (1977)
pCi ^{90}Sr l^{-1} = 0.75 - 0.0029 o/oo (1978)

The regression analysis showed significant or probably significant regression in all cases except in 1973, 1975, 1976, 1977 and 1978.

In analogy with ^{90}Sr, the following regression equations were found for ^{137}Cs in inner Danish waters:

pCi ^{137}Cs l^{-1} = 0.80 - 0.0043 o/oo (1972)
pCi ^{137}Cs l^{-1} = 0.60 + 0.012 o/oo (1973)
pCi ^{137}Cs l^{-1} = 0.54 + 0.018 o/oo (1974)
pCi ^{137}Cs l^{-1} = 0.64 + 0.010 o/oo (1975)

$$\text{pCi } {}^{137}\text{Cs } l^{-1} = 0.53 + 0.019 \text{ o/oo (1976)}$$
$$\text{pCi } {}^{137}\text{Cs } l^{-1} = 0.41 + 0.027 \text{ o/oo (1977)}$$
$$\text{pCi } {}^{137}\text{Cs } l^{-1} = -0.28 + 0.077 \text{ o/oo (1978)}$$

The regression analysis showed a significant regression in 1974, 1976, 1977 and 1978, probably significant in 1973 and 1975, and insignificant in 1972.

According to the above regression lines, the mean levels in Danish surface waters (16 o/oo salinity) were estimated at 0.70 pCi ^{90}Sr l^{-1} and 0.95 pCi ^{137}Cs l^{-1} in 1978. The corresponding levels in North Sea water (34 o/oo) were 0.65 and 2.3, respectively, and in Baltic water (9 o/oo) the equations gave 0.72 and 0.41, respectively.

In 1978 ^{134}Cs as well as ^{137}Cs was measured in Danish sea water samples collected around Sealand in June and December (cf. table 4.4.1). Cesium-137 came mainly from fallout and the reprocessing plant in Windscale. Cesium-134 came from Windscale; the releases during 1970-1976 were approx. 20% of the ^{137}Cs releases[10].

Let us assume that the fallout ^{137}Cs could be estimated from an interpolation of the ^{137}Cs levels in Baltic water (∿ 9 o/oo) and in North Atlantic water (∿ 35 o/oo). In 1978 we found 0.55 pCi ^{137}Cs l^{-1} Baltic water and 0.125 pCi ^{137}Cs l^{-1} Atlantic water (at the Faroes), i.e. for salinities between 20 and 35 o/oo the contribution from ^{137}Cs fallout would then vary from 0.37 to 0.12 pCi ^{137}Cs l^{-1}. If we apply this correction to the ^{137}Cs data in table 4.4.1 we get an estimate of the ^{137}Cs concentration in Danish sea water from Windscale. The ^{137}Cs fallout corrected mean ^{134}Cs/^{137}Cs ratio in inner Danish waters with a salinity greater than 20 o/oo was 0.076 $\pm$ 0.013 (1 SD) in 1978. The ^{134}Cs/^{137}Cs ratios in Windscale releases would have been 0.066 by August 1978 for the 1974 releases, 0.077 for 1975 and 0.086 for the 1976 releases; for the releases from 1973 and 1972 the ratio would have been 0.043 and 0.024 respectively in 1978. The observed ratio was highly significantly ($P > 99.9\%$) different from all these ratios except that from 1975.

Hence we conclude that the ^{137}Cs (and ^{134}Cs) from Windscale found in inner Danish waters in 1978 is likely to have arisen from releases in 1975, i.e. the transport time from Windscale to inner Danish waters has been approx. 3 years. If some ^{137}Cs in the Danish waters originated from Cap de la Hague in France the correction for this contribution would increase the $^{134}Cs/^{137}Cs$ ratio and the estimated transport time would be less than 3 years. However, the amounts of ^{137}Cs from Cap de la Hague in the North Sea are estimated to only a few percent of the Windscale contribution[10], and we thus assume it is justified to neglect the possible ^{137}Cs contributions from Cap de la Hague.

4.5. Soil samples

During 1978 the studies commenced in 1977 (Risø Report No. 386[1]) the sampling error associated with soil sampling was continued. In normal soil sampling, the samples are collected vertically by means of a 65 mm ϕ auger. As discussed in previous Risø Reports[1], this method involves a risk of contamination of the deeper low-activity samples by "high" activity surface soil, which is of special relevance to the nuclides with a high vertical activity gradient, such as ^{137}Cs and $^{239,240}Pu$. The Health and Safety Laboratory's trench method of soil sampling (HASL-300)[4] was applied to this study. Two trenches A and B, each approximately 4 m long, 1.5 m wide and 2 m deep, were in 1978 dug at St. Jyndevad (fig. 4.2). The trenches were approx. 2 km apart. After a careful shaving of one wall in each trench, to avoid contamination from the surface layers, two sets of samples in each trench were cored out horizontally in the shaved walls at the vertical depths: 5, 10, 15, 20, 25, 30, 40, 50, 65, 80 and 100 cm. The cores were collected with a 65 mm ϕ stainless steel auger to a horizontal depth of 45 cm; two cores were collected at each vertical depth so that the total sample represented a 90 cm long cylinder. The four sets of samples from the two trenches were called A_1, A_2, B_1 and B_2. The samples were analysed for ^{137}Cs (table 4.5.1) and for $^{239,240}Pu$ (cf. chapter 8). Table 4.5.2 shows the results of a sampling performed by the old method, where the samples are collected vertically.

Table 4.5.1. Cesium-137 in soil samples collected in June 1978 at St. Jyndevad

Depth in cm	A_1		A_2		B_1		B_2	
	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$
2.5	204	2.71	219	2.59	267	3.66	-	-
5	184	4.26	174	3.37	207	4.09	-	-
10	184	3.08	185	3.57	180	3.30	147	2.85
15	197	3.59	186	3.61	125	2.49	-	-
20	186	3.97	178	3.33	58	1.30	95	1.81
25	101	2.08	82	1.47	81	1.60	-	-
30	B.D.L.	B.D.L.	22	0.49	4 B	0.08 B	40	0.76
40	B.D.L.	B.D.L.	B.D.L.	B.D.L.	B.D.L.	B.D.L.	-	-
50	-	-	B.D.L.	B.D.L.	B.D.L.	B.D.L.	-	-
65	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-
100	B.D.L.	B.D.L.	-	-	-	-	-	-

The accumulated ^{137}Cs in mCi km^{-2} in the soil layers was calculated from the mCi $km^{-2}cm^{-1}$ figures by multiplication with 3.75 cm for samples until 5 cm, with 5 cm until 25 cm. For the 30 cm sample 7.5 cm was used and for the remaining samples 10 cm. Hence A_1 became 95.0 mCi ^{137}Cs km^{-2}, A_2: 90.1 and B_1: 78.2. The B.D.L.'s represent the cases when the count rate in the 662 keV ^{137}Cs peak was less than that expected from the contribution of ^{214}Bi to this peak.

Table 4.5.2. Cesium-137 in soil samples collected in June 1978 at St. Jyndevad

Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}
0-10	191	30.87
10-20	175	31.68
20-30	68	12.63
30-40	14.0	2.34
40-50	B.D.L.	B.D.L.
0-50		77.5

Table 4.5.3. Strontium-90 in soil samples collected in May 1977 at Skydebanen, Risø

Depth in cm	A_1		A_2		B_1		B_2	
	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$	pCi kg^{-1}	mCi $km^{-2}cm^{-1}$
2.5	280	1.96	294	2.50	212	1.60	-	-
5	222	2.17	184	2.10	208	2.29	-	-
10	254	2.33	137	1.38	168	1.31	84	0.76
15	184	1.69	34	0.38	116	1.00	-	-
20	16.6	0.175	10.1	0.106	36	0.31	24	0.26
25	14.9	0.158	5.9	0.058	15.2	0.165	-	-
30	4.4	0.040	9.0 B	0.105 B	5.3	0.060	3.2 A	0.032 A
40	3.4	0.034	3.2	0.030	5.0	0.053	-	-
50	1.80	0.015	1.88	0.019	3.1 A	0.027 A	-	-
65	8.2 B	0.12 B	5.4 B	0.081 B	26	0.22	-	-
80	90	1.45	0.56	0.009	7.9 B	0.11 B	-	-
100	B.D.L.	B.D.L.	3.7 A	0.059 A	53	0.86	-	-

The mean of the soil samplings (A_1, A_2, B_1 and the old method) was 85 $\pm$ 4 (1 SE) mCi ^{137}Cs km^{-2}. From ^{90}Sr analyses of precipitation samples collected at St. Jyndevad since 1962[1], the cumulated ^{137}Cs was estimated at 94 mCi km^2, assuming a $^{137}Cs/^{90}Sr$ ratio of 1.6. Soil samples collected at St. Jyndevand in 1975 and 1976 showed levels of 70, 81 and 132 mCi ^{137}Cs km^{-2}.

Contrary to the more clayish soil at Skydebanen, Risø-analysed in 1977, the sandy soil from St. Jyndevad did not show any exponential decrease in activity with depth. However, the total depths of penetration of ^{137}Cs (and Pu cf. 8) was for both soil types approx. 30 cm, and neither ^{137}Cs nor Pu were found below this depth.

It appears from table 4.5.3 that ^{90}Sr at Skydebanen in 1977 penetrated deeper than both ^{137}Cs and $^{239,240}Pu$. None of these radionuclides were detectable below 50 cm (cf Risø Report No 386[1])

4.6. Sediments

North of the outlet from the Waste Treatment Station at Risø (fig. 3.1.2.1), marine sediment samples were collected with a

Table 4.6.1. Cesium-137 in sediment samples collected in Roskilde Fjord in May 1978 (HAPS) (145 cm^2)

Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}
0-3	480 A	3.2 A
3-6	930	5.0
6-9	250 A	1.9 A
9-12	260 A	1.8 A
12-16	40 B	0.6 B
16-21	B.D.L.	B.D.L.
0-21 cm		12.5

HAPS sampler. Cores down to a depth of approx. 15 cm were analysed by Ge (γ) spectrometry. Table 4.6.1 shows the results, which were lower than those in previous years, due to a lower kg m^{-2} figure in 1978 than previously (cf. also 3.2.4).

5. DANISH FOOD AND VARIOUS VEGETATION

by A. Aarkrog

5.1. Strontium-90 and Cesium-137 in dried milk from the entire country

As in previous years, monthly samples of dried milk were collected from seven locations in Denmark (cf. fig. 5.1.1) but the analyses for ^{90}Sr were performed on pooled quarterly samples.

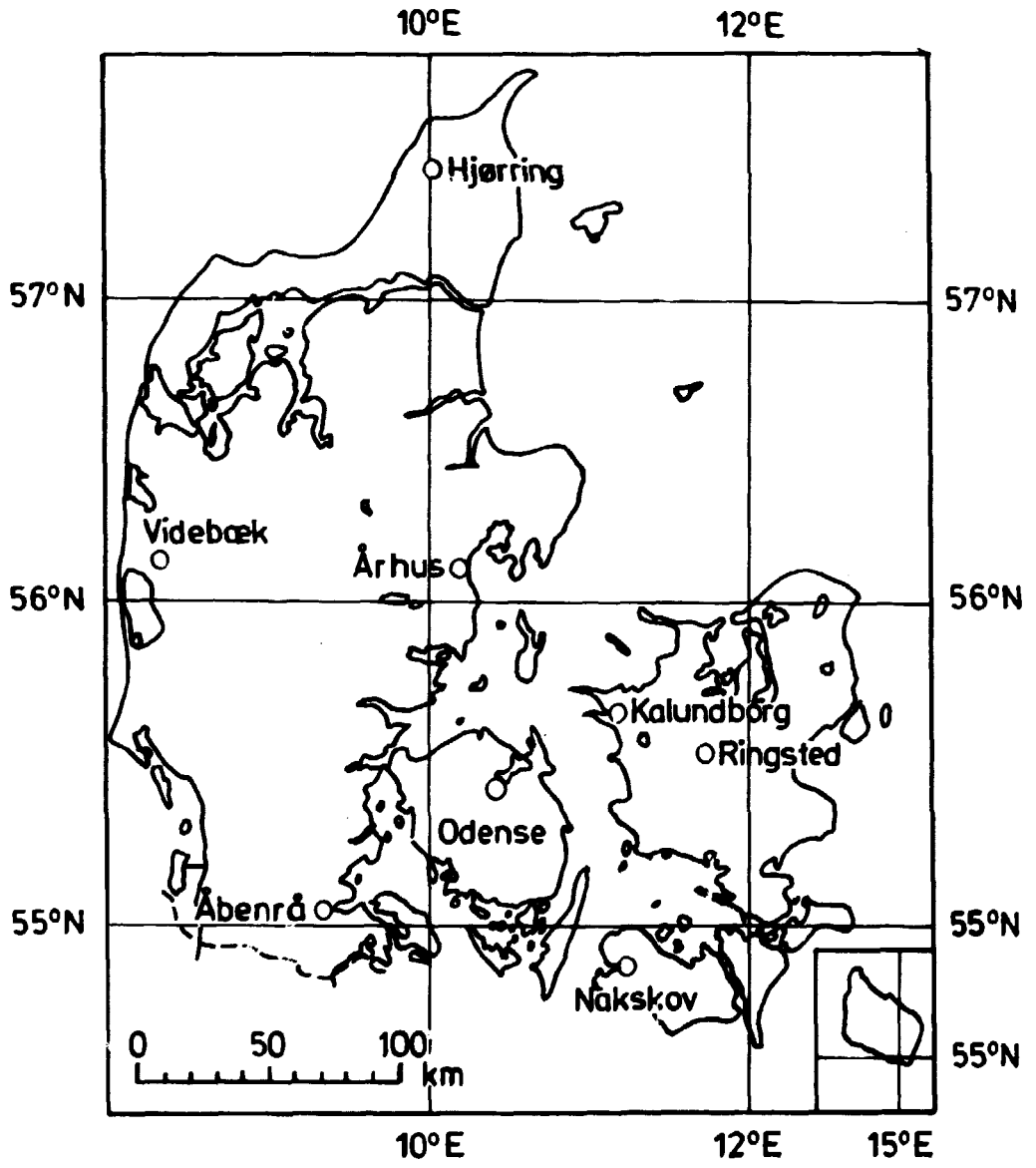

Fig. 5.1.1. Dried milk factories in Denmark.

Table 5.1.1 shows the results of the ^{90}Sr determinations and table 5.1.2 the analysis of variance of the results. As in recent years, the time variation was significant for S.U.; the levels in the second quarter of the year were the highest. The S.U. mean level in 1978 was 3.2 pCi ^{90}Sr (g Ca)$^{-1}$, i.e. 1.1 times the 1977 mean.

Table 5.1.1. Strontium-90 (pCi (g Ca)$^{-1}$) in Danish dried milk in 1978

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland Falster Møn	Mean
Jan							2.7*	
Feb							2.3*	
March	3.3	2.9	4.9	4.1	2.3	2.6	3.5	3.4
April							2.2*	
May							2.4*	
June	4.1	4.5	5.3	4.4	2.8	3.4	2.2	3.8
July							2.0*	
Aug							2.6*	
Sept	3.3	3.7	3.8	3.6	2.2	2.1	1.68	2.9
Oct							2.4*	
Nov							2.1*	
Dec	3.0	3.0	3.3	3.2	2.1	1.82	2.1	2.6
Mean	3.4	3.5	4.3	3.8	2.4	2.5	2.4	3.2

As 1 litre of milk contains 1.2 g Ca, the mean ^{90}Sr content in Danish milk produced in 1978 was 3.8 pCi l^{-1}. *not included in mean.

Table 5.1.2. Analysis of variance of ln pCi ^{90}Sr (g Ca)$^{-1}$ in dried milk in 1978 (from Table 5.1.1)

Variation	SSD	f	s^2	v^2	P
Between locations	1.579	6	0.263	11.401	>99.95%
Between quarters	0.523	3	0.174	7.553	>99.5%
Remainder	0.416	18	0.023		

Table 5.1.3. Cesium-137 (pCi (g K)$^{-1}$) in Danish dried milk in 1978

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland-Falster Møn	Mean
Jan	4.1	2.9	6.0	4.8	3.5	3.0	3.2	3.9
Feb	3.2	2.6	4.2	4.3	2.6	2.8	2.6	3.2
March	3.4	3.8	4.8	3.1	2.7	2.4	2.9	3.3
April	4.7	2.6	5.2	4.6	2.9	2.7	3.0	3.7
May	3.6	3.1	4.4	6.2	2.6	2.7	2.5	3.6
June	8.4	6.1	7.6	6.7	4.7	2.7	3.6	5.7
July	7.1	5.4	10.1	8.4	4.1	3.0	7.0	6.4
Aug	6.4	5.7	8.2	7.4	3.5	3.8	2.8	5.4
Sept	5.8	4.4	7.2	8.4	3.0	2.8	2.7	4.9
Oct	6.4	3.4	4.3	4.4	3.3	2.1	2.9	3.8
Nov	5.1	3.7	4.0	4.7	(2.6)	2.3	1.5	3.4
Dec	3.7	3.1	4.3	3.8	2.6	1.8	2.3	3.1
Mean	5.2	3.9	5.9	5.6	3.2	2.7	3.1	4.2

As 1 litre of milk contains approx. 1.66 g K, the mean ^{137}Cs content in Danish milk in 1978 was estimated at 7.0 pCi l^{-1}.

Table 5.1.4. Analysis of variance of ln ^{137}Cs (g K)$^{-1}$ in Danish dried milk (from Table 5.1.3)

Variation	SSD	f	s^2	v^2	P
Between locations	4.253	11	0.387	11.083	>99.95%
Between months	6.846	6	1.141	32.708	>99.95%
Remainder	2.268	65	0.035		

As previously, milk from eastern Denmark showed significantly lower levels than that from Jutland.

Table 5.1.3 shows the results of the ^{137}Cs determinations and table 5.1.4 the analysis of variance of the results. The M.U. mean level in 1978 was 4.2 pCi ^{137}Cs (g K)$^{-1}$, or 1.35 times the 1977 level.

Figures 5.1.2 - 5.1.5 show the S.U. and M.U. levels in dried milk compared with the predicted values (cf. Appendix C). The observed S.U. levels in 1978 were 0.91 times the predicted, while the observed M.U. levels were 1.26 times the predicted ones.

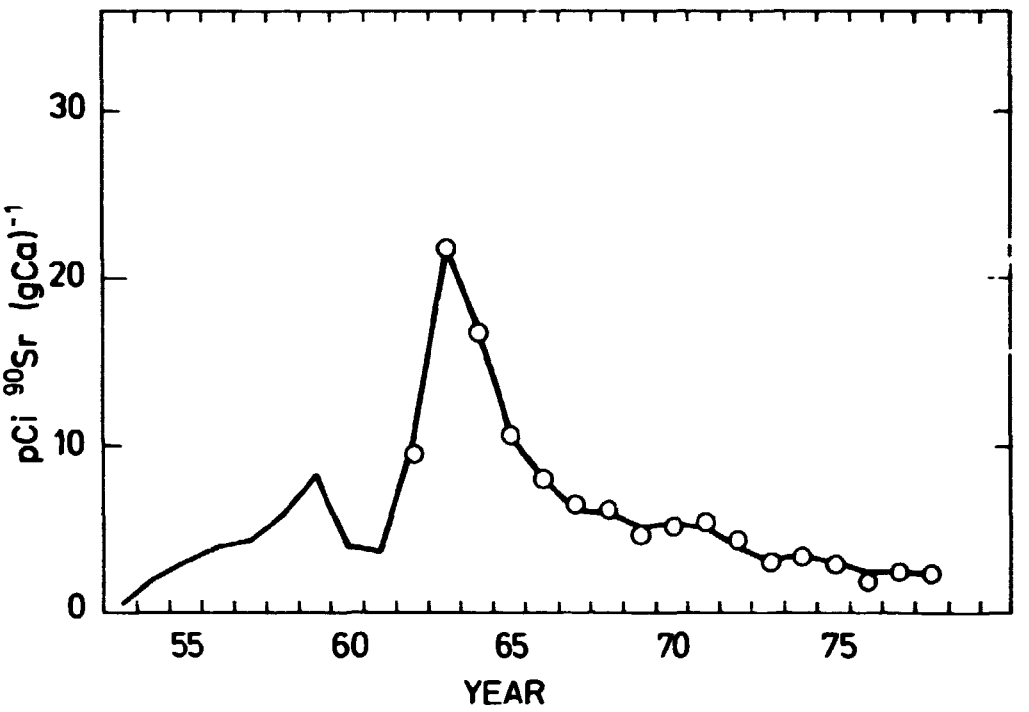

Fig. 5.1.2. Predicted and observed S.U. levels in dried milk from The Islands (May 1962-April 1979).

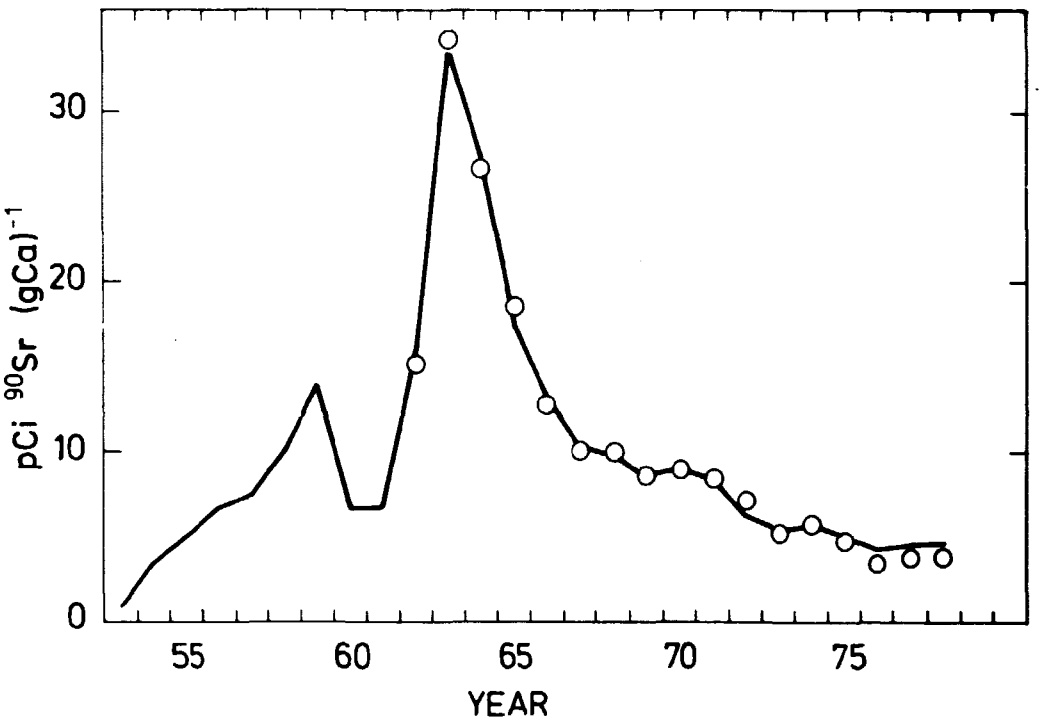

Fig. 5.1.3. Predicted and observed S.U. levels in dried milk from Jutland (May 1962-April 1979).

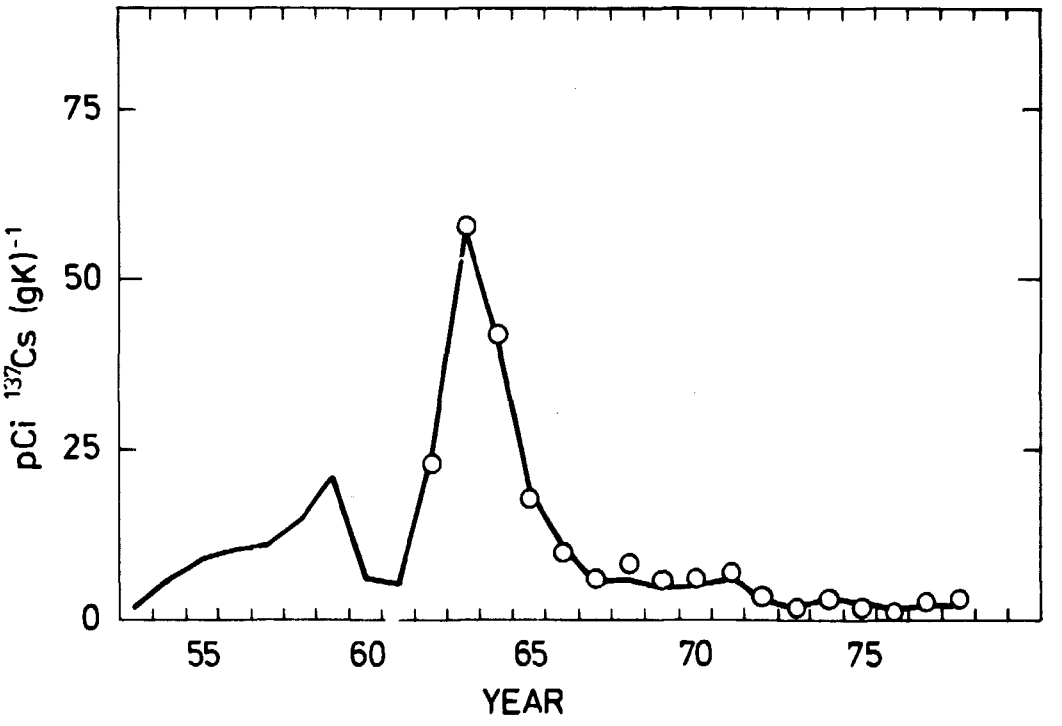

Fig. 5.1.4. Predicted and observed M.U. levels in dried milk from The Islands (May 1962-April 1979).

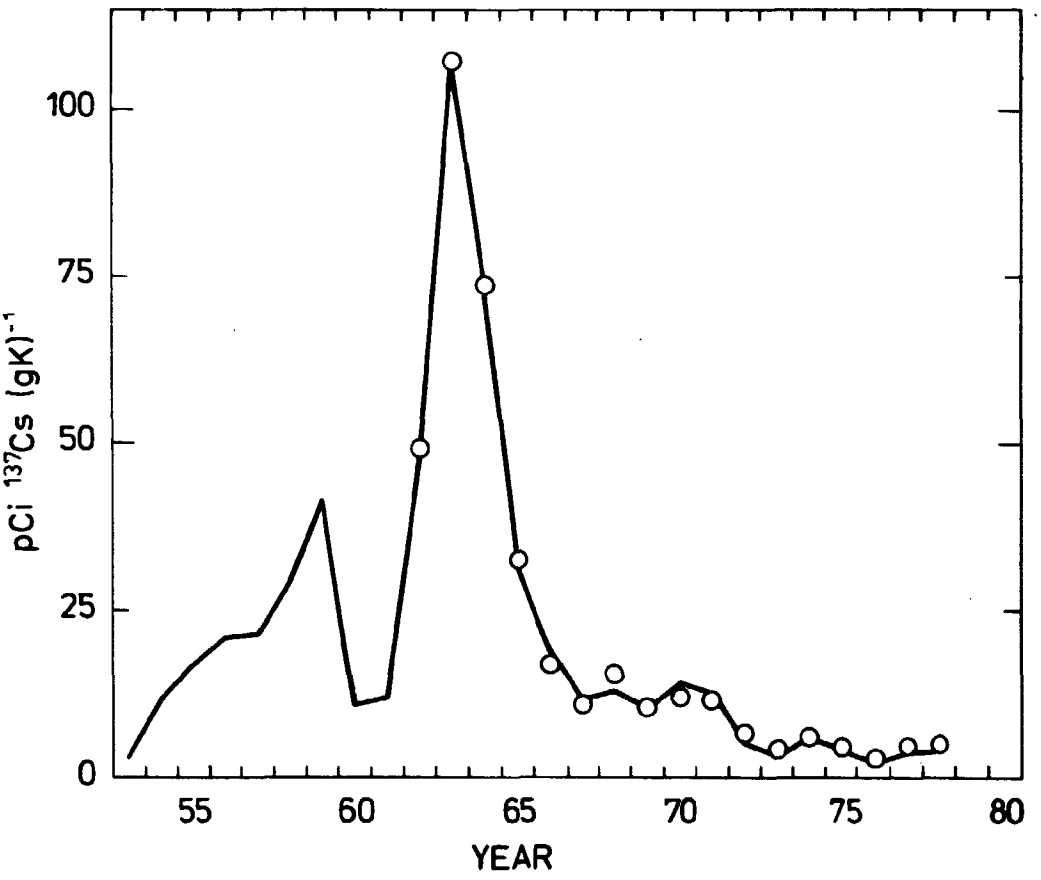

Fig. 5.1.5. Predicted and observed M.U. levels in dried milk from Jutland (May 1962-April 1979).

5.2. Fresh milk

No samples in 1978.

5.3. Strontium-90 and Cesium-137 in grain from the entire country

As in previous years, grain samples were obtained from the State experimental farms (cf. fig. 4.2). Strontium-90 was determined as previously (Risø Report No. 63[1]), and ^{137}Cs was measured on fresh samples by γ-spectrometry on a Ge detector. In a few samples ^{54}Mn was detectable.

Table 5.3.1 shows the measurements of ^{90}Sr in grain in 1978. According to Appendix B, approx. 2/3 of all rye in Denmark is grown in Jutland and 1/3 in the eastern part of the country. As regards, wheat, 4/5 is produced in eastern Denmark and 1/5 in Jutland. In the calculation of the means in tables 5.3.1 and 5.3.4, Jutland is represented by four rye samples and five wheat samples, while eastern Denmark contributes nine wheat and four rye samples. Thus the means in table 5.3.1 for wheat are a little higher than the production-weighted means for the country while the mean for rye is lower. Table 5.3.2 gives the analysis of variance of the S.U. figures and table 5.3.3 that of the pCi $^{90}Sr\ kg^{-1}$ grain figures.

Table 5.3.1. Strontium-90 in Danish grain in 1978

	Rye		Barley		Wheat		Oats	
	pCi $^{90}Sr\ kg^{-1}$	S.U.	pCi $^{90}Sr\ kg^{-1}$	S.U.	pCi $^{90}Sr\ kg^{-1}$	S.U.	pCi $^{90}Sr\ kg^{-1}$	S.U.
Tylstrup	29	88	21	46	s:39	s:100	30	32
Studsgård	29	77	41	90	81	146		
Ødum			s:18.1 w:11.6	s:35 w:23	w:10.5	w: 31	14.4	15.4
Askov	w:45	w:124	s:34 w:31	s:97 w:64	w:29	w:76	38	44
St. Jyndevad	26	74	31	88	w:34	w:81	22	26
Funen	13.7	42	7.7* 23	24* 49	20	50	26	27
Tystofte	w:12.0	w: 35	s:16.5 w:19.8	s:34 w:43	s:21 w:10.8	s:47 w:34	22	24
Ledreborg	13.7	43	16.0	36	s:35 w:15.7	s:88 w:48	19.6	24
Abed			9.5	15.9	s:11.3 w: 7.4	s:31 w:25	11.0	10.0
Bornholm	15.8	46	27	45	s:24 w:14.5	s:36 w:49	31	29
Mean	23	66	22	49	25	60	24	26

*Collected at Blangstedgård.

Table 5.3.2. Analysis of variance of ln S.U. in grain in 1978 (from Table 5.3.1)

Variation	SSD	f	s^2	v^2	P
Between species	3.728	3	1.243	24.550	>99.95%
Between locations	8.102	9	0.900	17.784	>99.95%
Spec. x loc.	1.215	24	0.051	0.530	
Remainder	0.765	8	0.096		

Table 5.3.3. Analysis of variance of ln pCi $^{90}Sr\ kg^{-1}$ grain in 1978 (from Table 5.3.1)

Variation	SSD	f	s^2	v^2	P
Between species	0.483	3	0.161	2.190	-
Between locations	8.220	9	0.913	12.411	>99.95%
Spec. x loc.	1.766	24	0.074	0.397	
Remainder	1.482	8	0.185		

Table 5.3.2 shows that the variations in S.U. between species and locations were significant. Rye and wheat showed the highest S.U. levels and oats the lowest. The pCi $^{90}Sr\ kg^{-1}$ figures did not show any significant difference between species (cf. table 5.3.3).

As in previous years, the variation with location was highly significant; the mean pCi $^{90}Sr\ kg^{-1}$ level for grain from Jutland was 1.8 times that in eastern Denmark. The observed pCi $^{90}Sr\ kg^{-1}$ levels in grain from 1978 were 1.15 times those predicted (cf. Appendix C).

Table 5.3.4. Cesium-137 in Danish grain in 1978

	Rye		Barley		Wheat		Oats	
	pCi $^{137}Cs\ kg^{-1}$	M.U.	pCi $^{137}Cs\ kg^{-1}$	M.U.	pCi $^{137}Cs\ kg^{-1}$	M.U.	pCi $^{137}Cs\ kg^{-1}$	M.U.
Tylstrup	35	7.8	15.0	3.3	s:21	s:5.2	17.5	4.5
Studsgård	52	12.5	38	6.9	38	9.9		
Ødum			s:26 w:35	s:4.9 w:8.4	13.2	3.1	20.3	4.4
Askov	59	13.5	s:32 w:38	s:7.6 w:10.3	22	6.1	21.6	6.4
St. Jyndevad	54	12.8	31	6.8	w:37	w:8.4	43	15.1
Punen	24	5.7	26 17.4*	5.0 3.6*	18.8	5.2	20.0	5.4
Tystofte	33	7.3	s:19.6 w:16.7	s:4.3 w:4.3	s:18.8 w:10.9	s:5.3 w:2.8	20.2	5.4
Ledreborg	31	7.3	16.8	3.5	s:15.9 w:17.4	s:4.6 w:4.1	23	4.9
Abed			22	4.3	s:15.4 w:17.2	s:4.0 w:3.8	14.7	3.4
Bornholm	28	6.9	20.1	5.1	s:13.5 w:17.2	s:3.9 w:4.6	31	7.3
Mean	40	9.2	25	5.6	19.7	5.1	23	6.3

*collected at Blangstedgård

Table 5.3.4 shows the measurements of ^{137}Cs in grain in 1978. The ^{137}Cs mean level in grain from 1978 was 1.2 times the level in 1977. Rye contained 1.6 times more ^{137}Cs in 1978 than in 1977, whereas the concentration in oats was 0.9 times the 1977 level.

Table 5.3.5. Analysis of variance of ln pCi ^{137}Cs $(g\ K)^{-1}$ in grain in 1978 (from Table 5.3.4)

Variation	SSD	f	s^2	v^2	P
Between species	1.347	3	0.449	7.843	>99.9%
Between locations	3.525	9	0.392	6.842	>99.95%
Spec. x loc.	1.374	24	0.057	0.963	
Remainder	0.476	8	0.059		

Table 5.3.6. Analysis of variance of ln pCi ^{137}Cs kg^{-1} in grain in 1978 (from Table 5.3.4)

Variation	SSD	f	s^2	v^2	P
Between species	1.816	3	0.605	11.362	>99.95%
Between locations	2.969	9	0.330	6.189	>99.95%
Spec. x loc.	1.279	24	0.053	1.231	
Remainder	0.346	8	0.043		

The observed pCi ^{137}Cs kg^{-1} levels in grain from 1978 were 1.22 times those predicted (cf. Appendix C).

Table 5.3.7 shows the ^{54}Mn levels in Danish grain. The ^{54}Mn was ascribed to the Chinese 4 Mt test on November 17, 1976.

Table 5.3.7. Manganese-54 in Danish grain in 1978. (Unit: pCi kg^{-1})

	Rye	Barley	Wheat	Oats
Tylstrup				
Studsgård	7.0 A			
Ødum		6.9 B		
Askov		w:7.7 B		
St. Jyndevad	8.0 A			
Blangstedgård		8.8 A		6.8*
Tystofte		w:8.4 B		
Ledreborg			w:6.6 A	
Abed		8.8 A		
Bornholm				

*Funen

5.4. Strontium-90 and Cesium-137 in bread from the entire country

In 1978, samples of white bread (75% extraction) and dark rye bread (100% extraction) were collected all over the country in June, and ^{90}Sr and ^{137}Cs were determined on pooled samples. The ^{137}Cs determinations were carried out on the ash by Ge γ-spectroscopy.

Table 5.4.1 shows the results. It is assumed that 1 kg flour yields approx. 1.35 kg bread[11] and that wheat flour of 75% extraction contains 20% of the ^{90}Sr and 50% of the ^{137}Cs found in wheat grain[1], while rye flour is 100% extraction. Hence we can compare the 1978 bread levels with the 1977 grain levels (cf. table 5.4.2).

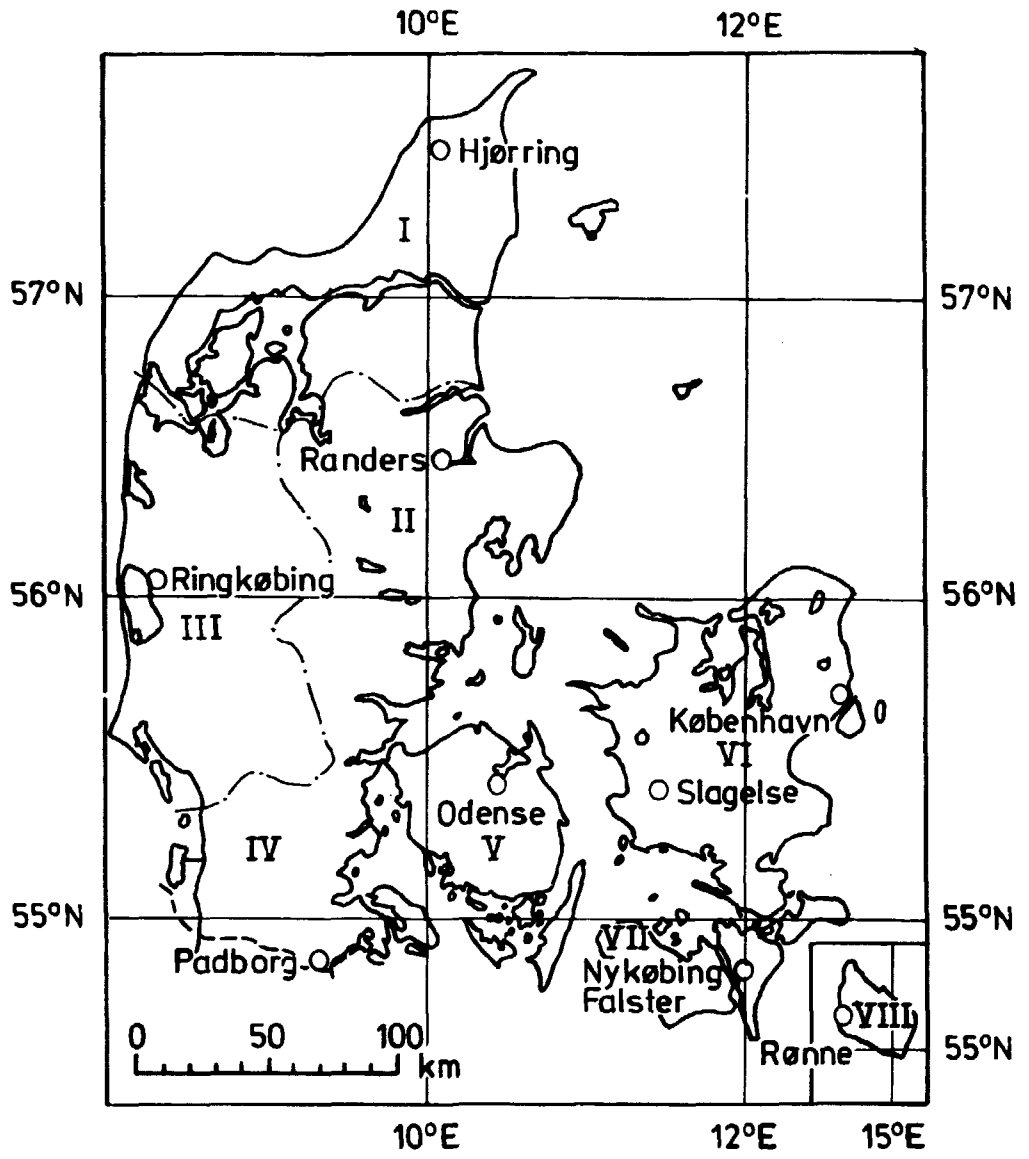

Fig. 5.4. Sample locations for bread and total diet.

Table 5.4.1. Strontium-90 and Cesium-137 in Danish bread collected in June 1978

Location	Rye bread				White bread			
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Jutland	18.9	6.4	16.0	6.5	4.6	2.3	6.0	4.4
Islands	15.2	5.1	23.4	7.1	5.5	2.5	10.2	5.9
Mean	17.0	5.8	19.7	6.8	5.0	2.4	8.1	5.2
Copenhagen	6.6	3.9	14.6	5.3	4.9	3.5	6.0	3.9
Population-weighted mean	14.6	5.4	17.8	6.4	5.0	2.7	7.2	4.7

Table 5.4.2. A comparison between ^{90}Sr and ^{137}Cs levels in bread and grain in 1978

Nuclide	Species	Bread activity in June 1978 calculated as grain in pCi kg^{-1} (cf. text)	Activity in grain from harvest 1977[1] pCi kg^{-1}	"Bread"/grain ratio
^{90}Sr	Wheat	33.7	25	1.3
	Rye	19.7	26	0.8
^{137}Cs	Wheat	19.4	18	1.1
	Rye	24.0	25	1.0

5.5. Strontium-90 and Cesium-137 in potatoes from the entire country

The samples of potatoes were collected in September from ten of the State experimental farms (cf. fig. 4.2) and analysed for ^{90}Sr and ^{137}Cs (γ-spectroscopy of bulked samples of the ash).

Table 5.5.1. Strontium-90 and Cesium-137 in Danish potatoes in 1978

	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Tylstrup	2.00	18.5		
Studsgård	2.50	67		
Ødum	2.98	68	5.0	1.16
Askov	2.10	41		
St. Jyndevad	1.98	25		
Blangstedgård	0.97	22		
Tystofte	2.36	35		
Ledreborg	1.75	43	2.6	0.53
Abed	1.34	25		
Åkirkeby	1.84	46		
Mean	1.98	39	3.8	0.85

Table 5.5.1 shows the ^{90}Sr and ^{137}Cs contents in potatoes. The mean contents for the country were 2.0 pCi ^{90}Sr kg^{-1}, or 39 S.U., and 3.8 pCi ^{137}Cs kg^{-1}, or 0.85 M.U. The ^{90}Sr levels were nigher than those in 1977, while the ^{137}Cs concentrations were lower.

5.6. Strontium-90 and Cesium-137 in vegetables and fruit from the entire country

In 1978, as in previous years, vegetables and fruit were collected in the autumn from eight larger provincial towns, one in each of the eight zones.

The γ-measurements were performed on bulked ash samples representing the entire country (cf. table 5.6.2).

Table 5.6.1. Strontium-90 in vegetables and fruits collected in September 1978

Zone	Cabbage		Carrot		Apples	
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.
I: N. Jutland	10.2	29.3	9.1	33	0.78	14
II: E. Jutland	12.1	20.0	18.6	79	1.55	42
III: W. Jutland	5.6	10.3	16.5	64	0.97	28
IV: S. Jutland	5.5	10.1	4.1	16	1.25	20
V: Funen	5.1	9.6	10.5	34	1.06	19
VI: Zealand	2.8	7.9	4.7	18	0.64	15
VII: Lolland-Falster	9.9	32.2	7.8	27	0.30	10
VIII: Bornholm	7.1	16.4	18.0±2.2	62±8	0.84	13
Mean	7.3	17.0	11.2	42	0.92	20
Copenhagen	6.1	12.1	1.7±0.1	6.8±0.6	0.45	11
Population-weighted mean	6.9	14.4	8.9	35	0.86	21

Table 5.6.2. Cesium-137 in Danish vegetables and fruits in 1978

Cabbage		Carrots		Apples	
pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.
1.71	0.78	1.66	0.74	3.2	2.7

The highest ^{90}Sr levels (pCi kg^{-1}) were found in carrots, the lowest in apple.

Table 5.6.3 shows a calculation of the mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1978. The levels are the population-weighted means.

Table 5.6.3. Calculated ^{90}Sr and ^{137}Cs mean levels in vegetables in 1978

Daily intake in g	Species	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
50	Leaf vegetables (cabbage)	7.3	17	1.7	0.8
30	Root vegetables (carrot)	11.2	42	1.7	0.7
40	Pea (1977 data)	3.6	12	1.6	0.1
120	Vegetables total	7.0	22	1.7	0.54

The 1978 levels in Danish fruit were calculated from apples and the mean levels in Danish fruit were thus 0.9 pCi ^{90}Sr kg^{-1} and 3.2 pCi ^{137}Cs kg^{-1}. The observed pCi ^{90}Sr kg^{-1} levels in vegetables and fruits in 1978 were 0.93 times those predicted (cf. Appendix C). In the case of ^{137}Cs, the observed values were 1.08 times the predicted ones.

5.7. Strontium-90 and Cesium-137 in total diet from the entire country

In 1978 total-food samples representing an average Danish diet according to E. Hoff-Jørgensen (cf. Appendix B in Risø Report No. 63[1]) were collected from eight towns each representing one of the eight zones (cf. fig. 5.2.1) and from Copenhagen. The sampling took place as previously in June and December.

Table 5.7.1. Strontium-90 and Cesium-137 in Danish total diet collected in June 1978

Zone		pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr day^{-1}	g Ca day^{-1}	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs day^{-1}
I:	N. Jutland	4.5±0.1	7.2±0.2	1.61±0.00	3.89	15.2
II:	E. Jutland	6.2±0.7	9.7±1.2	1.58±0.00	3.31	10.9
III:	W. Jutland	5.2±0.0	8.5±0.0	1.63±0.01	5.14	21.1
IV:	S. Jutland	4.9±0.4	7.8±0.6	1.58±0.00	4.29	15.5
V:	Funen	4.3±0.3	7.3±0.5	1.69±0.01	3.99	16.3
VI:	Zealand	4.3±0.5	7.0±0.8	1.62±0.01	3.94	15.2
VII:	Lolland-Falster	3.8±0.1	6.6±0.2	1.72±0.01	4.00	15.1
VIII:	Bornholm	5.3±0.2	8.6±0.4	1.64±0.00	4.15	16.9
Mean		4.8	7.8	1.63	4.09	15.8
Copenhagen		4.0±0.3	6.4±0.4	1.60±0.02	3.20	11.8
Population-weighted mean		4.7	7.6	1.62	3.83	14.5
Relative error due to analysis		11%	11%	1%		

Table 5.7.2. Strontium-90 and Cesium-137 in Danish total diet collected in December 1978

Zone		pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr day^{-1}	g Ca day^{-1}	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs day^{-1}
I:	N. Jutland	3.6±0.2	6.1±0.2	1.68±0.01	6.20	23.5
II:	E. Jutland	3.7±0.0	5.8±0.1	1.58±0.02	4.07	16.3
III:	W. Jutland	4.3±0.1	7.6±0.0	1.77±0.02	4.64	17.9
IV:	S. Jutland	4.3±0.3	7.1±0.4	1.63±0.00	4.72	16.2
V:	Funen	3.8±0.1	7.6±0.1	1.97±0.01	3.82	14.6
VI:	Zealand	4.3±0.2	7.2±0.4	1.68±0.02	4.06	15.2
VII:	Lolland-Falster	3.3±0.0	5.2±0.0	1.58±0.02	4.12	15.0
VIII:	Bornholm	3.9±0.1	6.1±0.2	1.55±0.01	2.61	10.4
Mean		3.9	6.6	1.68	4.28	16.1
Copenhagen		3.7±0.0	5.9±0.1	1.60±0.01	3.54	13.2
Population-weighted mean		3.9	6.6	1.68	4.22	16.0
Relative error due to analysis		5%	5%	1%		

Tables 5.7.1 and 5.7.2 show the results. The diet levels from Jutland were a little higher than those from the Islands.

Figure 5.7.1 show the zone mean S.U. levels (not population-weighted) in total diet compared with the predicted values (cf. Appendix C).

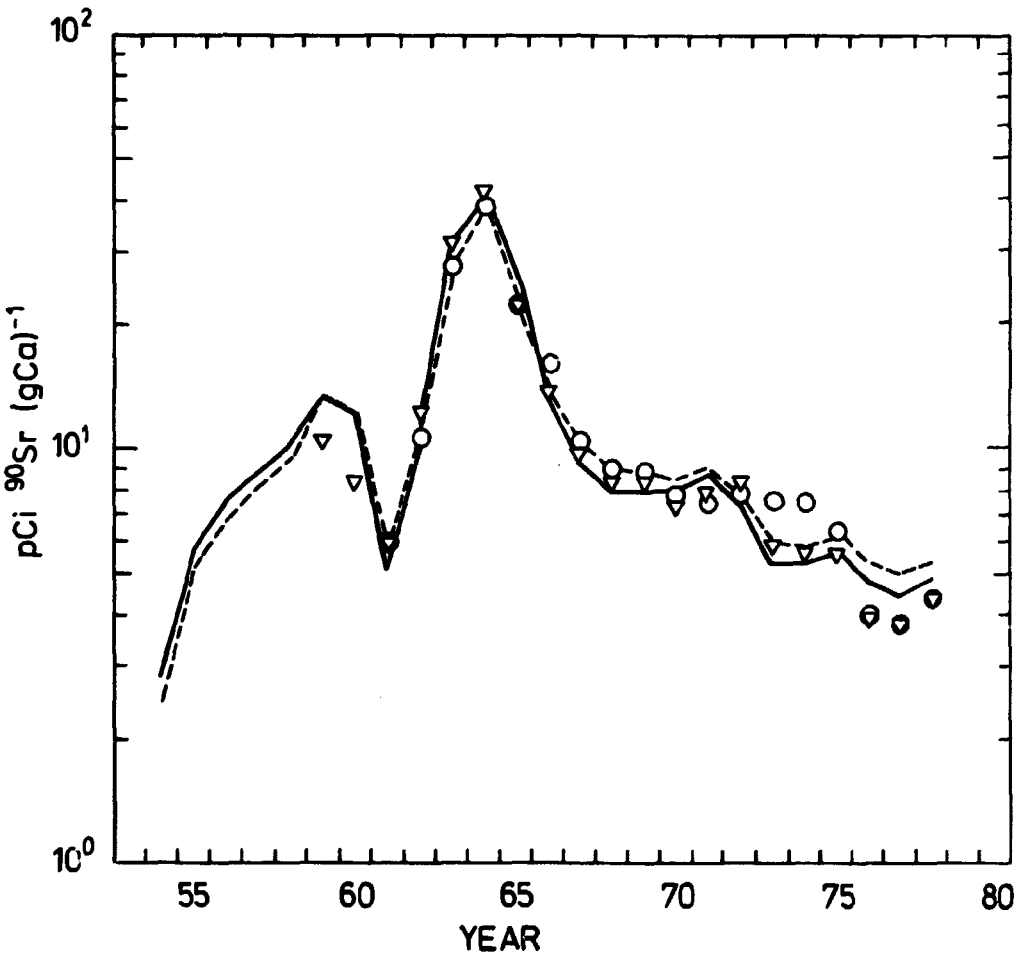

Fig. 5.7.1. Predicted and observed ^{90}Sr levels in the Danish total diet. The dotted curve represents the predicted values for "Diet C" (cf. Tables 5.7.1 and 5.7.2) and the circles are the corresponding observed values. The unbroken curve represents the predicted values for "Diet P" (cf. Table 5.9.3), and the trinagles the corresponding observed values.

The ^{90}Sr 1978 levels in the total diet were approx. 10% higher than the 1977 levels, and the ^{137}Cs levels were 40% higher.

From the total-diet sampling it is possible to estimate the mean levels of ^{90}Sr and ^{137}Cs in the Danish diet in 1978. For the period January-March 1978, the ^{90}Sr level in the total diet is assumed to have been equal to that measured in December 1977, Risø Report No. 386[1]. For the period April-September we assume the level to have corresponded to that measured in June 1978. The December 1978 figures are taken to represent the last three months of the year. The population-weighted mean of ^{90}Sr in total-diet samples was 3.8 pCi ^{90}Sr (g Ca)$^{-1}$ in December 1977. Hence the mean content in the total diet in 1978 was 4.3 pCi ^{90}Sr (g Ca)$^{-1}$, or 6.9 pCi ^{90}Sr (day)$^{-1}$.

Similarly, the ^{137}Cs content in the Danish diet in 1978 was estimated to be 14.5 pCi ^{137}Cs (day)$^{-1}$ or 3.8 pCi ^{137}Cs (g K)$^{-1}$.

5.8. Strontium-90 and Cesium-137 in miscellaneous foodstuffs

5.8.1. Strontium-90 and Cesium-137 in meat

Pork and beef samples were collected in Copenhagen in three large shops in June and December. Table 5.8.1 shows the results. As compared with 1977, the mean levels were generally higher in 1978.

Table 5.8.1. Strontium-90 and Cesium-137 in Danish meat collected in Copenhagen in 1978

Month	Pork				Beef			
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
June	0.95	6.4	49	17.7	1.14	7.5	36	12.5
December	1.51	13.1	27	8.0	1.05	5.4	20	6.4
Mean	1.23	9.8	38	12.9	1.10	6.4	28	9.4

5.8.2. Strontium-90 and Cesium-137 in fish

Fish samples were collected in the North Sea and in inner Danish waters. Tables 5.8.2.1 and 5.8.2.2 show the results. The mean levels of the two samplings were 0.8 pCi $^{90}Sr\ kg^{-1}$ and 99 pCi $^{137}Cs\ kg^{-1}$.

Table 5.8.2.1. Strontium-90 and Cesium-137 in fish from the North Sea purchased in Esbjerg in 1978

Species		pCi $^{90}Sr\ kg^{-1}$	S.U.	pCi $^{137}Cs\ kg^{-1}$	M.U.
Flounder	flesh	0.76	0.75	50	14
	bone	-	0.55	-	-
Herring (total)		0.64	0.47	91	29
Cod	flesh	0.97	0.47	80	21
	bone	-	0.29	-	-

Table 5.8.2.2. Strontium-90 and Cesium-137 in fish from inner Danish waters in 1978

Species		pCi $^{90}Sr\ kg^{-1}$	S.U.	pCi $^{137}Cs\ kg^{-1}$	M.U.
Flounder	flesh	1.00	0.88	87	20
	bone	-	1.23	-	-
Herring	flesh	0.36	0.62	139	35
	bone	-	1.38	-	-
Cod	flesh	1.16	1.21	148	35
	bone	-	1.09	-	-

It is estimated from the prediction models for ^{137}Cs in fish[21] that fallout contributed approx. one third to one half of the ^{137}Cs level observed the remaining part ~60 pCi $^{137}Cs\ kg^{-1}$ was attributed to releases from Windscale.

5.8.3. Strontium-90 and Cesium-137 in various foods

As compared with the corresponding sampling in 1974, banana and orange showed a little lower levels, whereas tea and coffee showed definitely higher concentrations. The levels in these two products were similar to those observed in 1972 and 1974[1].

Table 5.8.3. Strontium-90 and Cesium-137 in various foods collected in Copenhagen in December 1978

Sample	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Banana	0.32	3.5	1.5	0.44
Orange	7.4	14.4	1.1	0.62
Rize	0.22	4.2	6.2	4.7
Oats Grits	9.9	3.0	15.2	4.0
Coffee	20.7	41	23	1.29
Tea	45.4	12.2	167	13.1
Chicken	0.41	1.9	11.3	4.4
Eggs	0.45	0.8	1.34	1.08
Chicken bone	-	2.2	-	-

5.9. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Denmark in 1978

5.9.1. The annual quantities

The annual quantities are calculated by multiplication of the daily quantities by 365 (as stated by E. Hoff-Jørgensen, cf. Risø Report No. 63, table B[1]).

Table 5.9.1. Estimate of the ^{90}Sr content in grain products consumed per capita in 1978

Type	Fraction from harvest 1977			Fraction from harvest 1978			Total
	kg flour	pCi kg^{-1}	pCi	kg flour	pCi kg^{-1}	pCi	pCi
Rye flour (100% extraction)	21.9	26	569	7.3	23	168	737
Wheat flour (75% extraction)	32.9	5.0	165	10.9	5.0	54	219
Grits	5.5	11.6	64	1.8	8.0	14	78
Total	60.3	13.2	798	20.0	11.8	236	1034

5.9.2. Milk and cream

The ^{90}Sr and ^{137}Cs contents per kg milk were calculated from the annual mean values for dried milk (cf. tables 5.1.1 and 5.1.3). 1 kg ∿ 1 l milk, containing approx. 1.2 g Ca and 1.66 g K. Hence the mean contents in milk were 3.8 pCi ^{90}Sr kg^{-1} and 7.0 pCi ^{137}Cs kg^{-1}.

Table 5.9.2. Estimate of the ^{137}Cs content in grain products consumed per capita in 1978

Type	Fraction from harvest 1977			Fraction from harvest 1978			Total
	kg flour	pCi kg^{-1}	pCi	kg flour	pCi kg^{-1}	pCi	pCi
Rye flour (100% extraction)	21.9	25	548	7.3	40	292	840
Wheat flour (75% extraction)	32.9	9.0	296	10.9	10.0	109	405
Grits	5.5	11.7	64	1.8	10.4	19	83
Total	60.3	15.0	908	20.0	21.0	420	1328

5.9.3. Cheese

One kg of cheese contains approx. 8.5 g Ca and 1.2 g K. The ^{90}Sr and ^{137}Cs contents in cheese were calculated from these figures and from the S.U. and M.U. levels in dried milk (cf. tables 5.1.1 and 5.1.3). One kg of cheese appeared to contain 27.2 pCi ^{90}Sr and 5.0 pCi ^{137}Cs.

Table 5.9.3. Estimate of the mean content of ^{90}Sr in the human diet in Denmark in 1978

Type of food	Annual quantity in kg	pCi ^{90}Sr per kg	Total pCi ^{90}Sr	Percentage of total pCi ^{90}Sr in food
Milk and cream	164.0	3.8	623	23.1
Cheese	9.1	27.2	248	9.2
Grain products	80.3	12.9	1034	38.3
Potatoes	73.0	2.0	146	5.4
Vegetables	43.8	7.0	307	11.4
Fruit	51.1	1.8	92	3.4
Meat	54.7	1.2	66	2.4
Eggs	10.9	0.5	5	0.2
Fish	10.9	0.8	9	0.3
Coffee and tea	5.5	29	160	5.9
Drinking water	548	0.02	11	0.4
Total			2701	

The mean calcium intake was estimated at 620 g (approx. 200-250 g Creta praeparata). Hence the ^{90}Sr/Ca ratio in the total diet was 4.4 S.U. in 1978.

5.9.4. Grain products

Tables 5.8.1 and 5.9.2 show the estimates of ^{90}Sr and ^{137}Cs, respectively, in grain products consumed in 1978. From these tables, the activity levels in grain products were estimated at 12.9 pCi ^{90}Sr kg^{-1} and 16.5 pCi ^{137}Cs kg^{-1}.

Table 5.9.4. Estimate of the mean content of ^{137}Cs in the human diet in Denmark in 1978

Type of food	Annual quantity in kg	pCi ^{137}Cs per kg	Total pCi ^{137}Cs	Percentage of total pCi ^{137}Cs in food
Milk and cream	164.0	7.0	1148	17.9
Cheese	9.1	5.0	46	0.7
Grain products	80.3	16.5	1328	20.7
Potatoes	73.0	3.8	277	4.3
Vegetables	43.8	1.7	74	1.2
Fruit	51.1	2.7	138	2.2
Meat	54.7	35	1914	29.9
Eggs	10.9	1.3	14	0.2
Fish	10.9	99	1079	16.8
Coffee and tea	5.5	71	390	6.1
Drinking water	548	0	0	0
Total			6408	

As the approximate intake of potassium was 1365 g, the pCi ^{137}Cs $(g\ K)^{-1}$ ratio was approx. 4.7. The daily mean intake in 1978 was 17.6 pCi ^{137}Cs per capita.
If we neglect the contribution of ^{137}Cs to fish from Windscale (5.8.2) the daily ^{137}Cs intake with total diet in 1978 would decrease with approx. 10 per cent.

5.9.5. Potatoes

The figures in table 5.5.1 were used, i.e. 2.0 pCi $^{90}Sr\ kg^{-1}$ and 3.8 pCi $^{137}Cs\ kg^{-1}$.

5.9.6. Vegetables

Table 5.6.3 shows the calculation of ^{90}Sr and ^{137}Cs in Danish vegetables consumed in 1978. The mean contents were 7.0 pCi $^{90}Sr\ kg^{-1}$ and 1.7 pCi $^{137}Cs\ kg^{-1}$.

5.9.7. Fruit

The levels in imported fruit in 1978 are assumed to be equal to the mean levels found in oranges and bananas collected in Copenhagen in 1978, i.e. 3.9 pCi $^{90}Sr\ kg^{-1}$ and 1.3 pCi $^{137}Cs\ kg^{-1}$. The mean levels in Danish fruit (apples) in 1978 were 0.9 pCi $^{90}Sr\ kg^{-1}$ and 3.2 pCi $^{137}Cs\ kg^{-1}$ (cf. 5.6). The daily mean consumption of fruit consisted of 100 g of Danish and 40 g of foreign origin. Hence the mean contents in fruit were 1.8 pCi $^{90}Sr\ kg^{-1}$ and 2.7 pCi $^{137}Cs\ kg^{-1}$.

5.9.8. Meat

The annual mean values of ^{90}Sr and ^{137}Cs in meat were calculated from table 5.8.1: 1.2 pCi $^{90}Sr\ kg^{-1}$ and 35 pCi $^{137}Cs\ kg^{-1}$. (In a Danish diet meat comprises 2/3 pork and 1/3 beef).

5.9.9. Fish

The ^{90}Sr and ^{137}Cs contents in fish are estimated from 5.8.2 at 0.8 pCi $^{90}Sr\ kg^{-1}$ and 99 pCi $^{137}Cs\ kg^{-1}$.

5.9.10. Eggs

The contents of activity in eggs were estimated from 5.8.3. The levels were 0.5 pCi $^{90}Sr\ kg^{-1}$ and 1.3 pCi $^{137}Cs\ kg^{-1}$.

5.9.11. Coffee and tea

One third of the total consumption consists of tea and two thirds of coffee. The mean contents were 29 pCi $^{90}Sr\ kg^{-1}$ and 71 pCi $^{137}Cs\ kg^{-1}$.

5.9.12. Drinking water

The ^{90}Sr level (population-weighted mean) found in drinking water collected in June 1973 was used as the mean level for drinking water, i.e. 0.02 pCi $^{90}Sr\ l^{-1}$. The ^{137}Cs content in drinking water is assumed to be negligible.

5.9.13. Discussion

Tables 5.9.3 and 5.9.4 show the estimates of ^{90}Sr and ^{137}Cs in the Danish diet in 1978. The figures should be compared with the levels calculated from the total-diet samples (cf. 5.7). The ^{90}Sr estimates obtained by the two methods (cf. also fig. 5.7.1) were 4.4 S.U. and 4.3 S.U., respectively, and the ^{137}Cs estimates were 17.6 pCi ^{137}Cs day^{-1} and 14.5 pCi ^{137}Cs day^{-1}.

The relative contributions of ^{90}Sr from milk products (∿ 32%) and from grain (38%) were similar to those in 1977. The contribution from potatoes, other vegetables, and fruit was ∿ 20%, i.e. also nearly unchanged from 1977. The relative contribution of ^{137}Cs in the total diet changed from 1977 to 1978 as follows: milk products were unchanged (19 to 19%), grain products increased from 14 to 21%, and meat was unchanged (30 to 30%). Fish contributed nearly 17% to the total ^{137}Cs intake in 1978, and is thus just as important a source of ^{137}Cs as milk products.

5.10. Grass collected around Risø

Table 5.10 shows the ^{90}Sr content in grass ash from Zealand in 1978. The mean ^{90}Sr activity was 2.5 pCi ^{90}Sr $(g\ ash)^{-1}$, or 53 S.U., as compared with 1.8 pCi $(g\ ash)^{-1}$, or 31 S.U., in 1977, i.e. the 1978 level was approx. 50% higher than the 1977 level. Figure 5.11 shows the ^{90}Sr concentration in grass since 1957.

Table 5.10. Strontium-90 in grass from Zealand, 1978

	pCi ^{90}Sr $(g\ ash)^{-1}$	pCi ^{90}Sr $(g\ Ca)^{-1}$
Jan-March	3.35	83
April-June	2.60	59
July-Sept	2.31	34
Oct-Dec	1.76	35
Mean	2.50	53

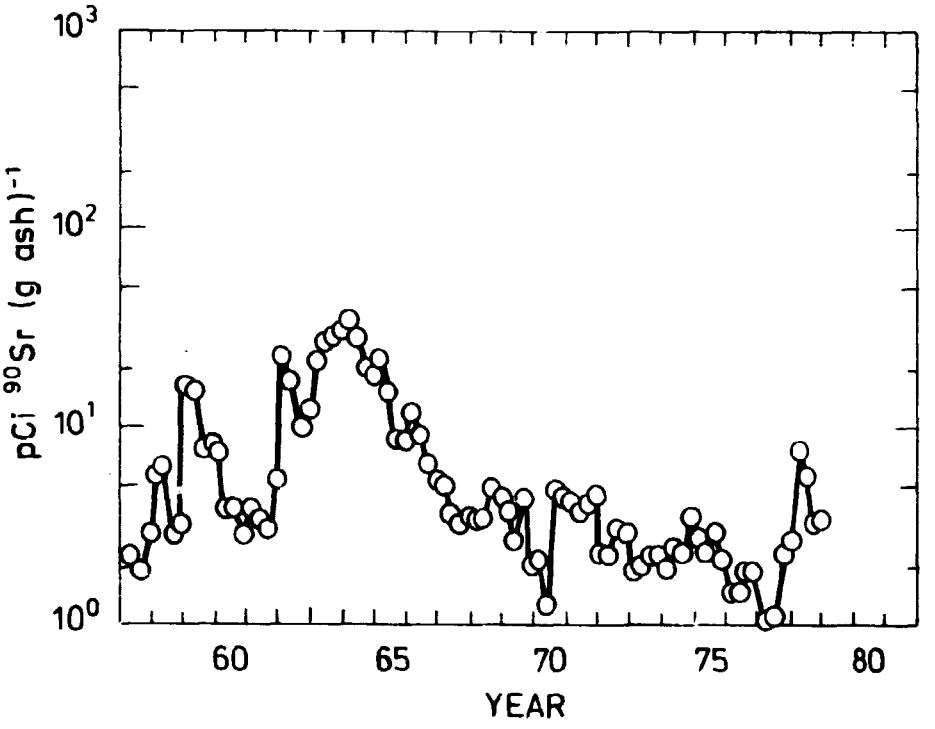

Fig. 5.11. Quarterly ^{90}Sr levels in grass, 1957-1978.

5.11. Sea plants collected in Roskilde Fjord

Figure 5.12 shows the S.U. levels in sea plants since 1959 and table 5.11 the results for 1978. The level in Fucus vesiculosus was 6.2 pCi ^{90}Sr (g Ca)$^{-1}$, and in Zostera marina 2.9 pCi ^{90}Sr (g Ca)$^{-1}$.

Table 5.11. Strontium-90 and Cesium-137 in sea plants from Roskilde Fjord in 1978

Location	Species	pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr (g ash)$^{-1}$	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs (g ash)$^{-1}$
I	Fucus vesiculosus	6.2	0.72	7.4	1.32
IX	Zostera marina	2.9	0.157	1.3 B	0.26 B

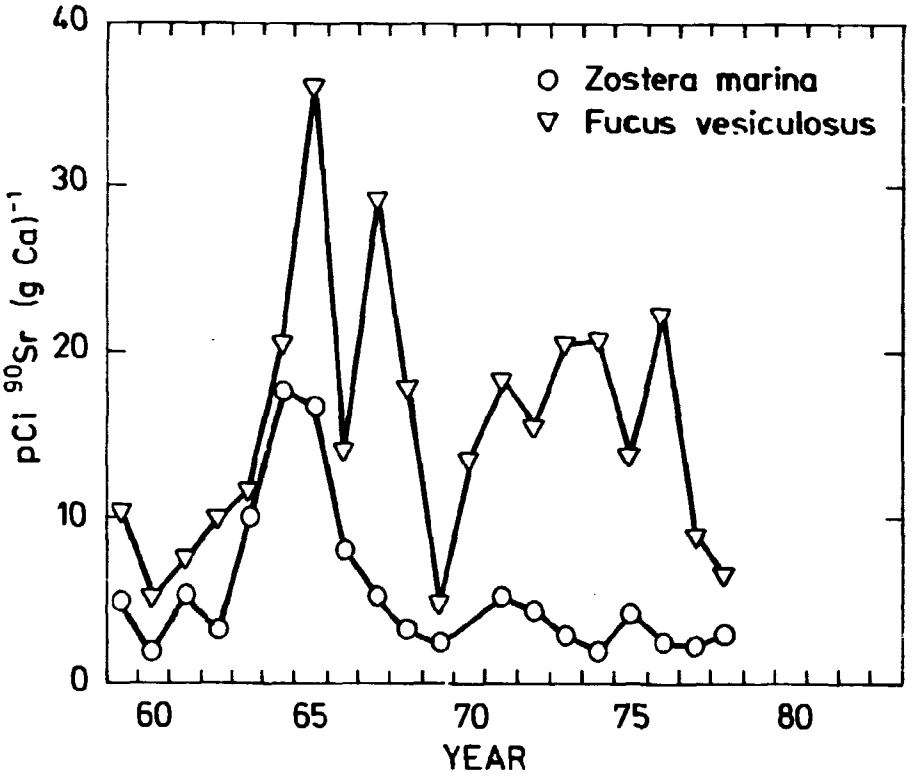

Fig. 5.12. Strontium-90 in sea plants from Roskilde Fjord, 1959-1978.

6. STRONTIUM-90 AND CESIUM-137 IN MAN IN 1978

by A. Aarkrog and J. Lippert

6.1. Strontium-90 in human bone

The collection of human vertebrae from the institutes of forensic medicine in Copenhagen and Århus was continued in 1978. As in the total-diet survey (cf. 5.7), the country was divided into eight zones. The samples were divided into five age groups: new-born (< 1 month), infants (1 month-4 years), children and teenagers (5 - 19 years), adults (≤ 29 years), and adults (> 29 years), however, no samples of new-borns bone were obtained in 1978.

Tables 6.1.2 - 6.1.5 show the results for the four groups.

Table 6.1.1. Strontium-90 in bone from new-born children (< 1 month old) in 1978

No samples.

Table 6.1.2. Strontium-90 in bone from infants (≤ 4 years) in 1978

Zone	Age in years and months	Month of death	Sex*	pCi ^{90}Sr (g Ca)$^{-1}$
VI	2 m	11	M,F	0.82
VI	2-4 m	1	F,M,M	0.68
VI	3-4 m	Dec 1977	M,M	0.58
VI	3 m	Dec 1977	M	1.23
VI	6 m	1	M,F	0.84
VI	18 m	Dec 1977	F	0,69

*Most analyses consisted of two or more samples as indicated in this column.

Table 6.1.3. Strontium-90 in bone from children and teenagers (≤ 19 years) in 1978

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
II	10	3	M	0.72
II	12	3	M	0.78
II	17	2	M	1.15
VI	1	11	-	0.65
VI	14	11	M	0.95
VI	14	3	M	1.59
VI	16	1	M	1.21
VI	17	2	F	0.93

Table 6.1.4. Strontium 90 in vertebrae from adults (≤ 29 years) in 1978

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
III	27	11	M	0.89
VI	29	1	F	0.86
VI	22	1	F	0.93
VI	21	2	F	1.15
VI	28	2	M	0.76
VI	29	2	M	0.74
VI	23	10	M	1.28
VI	22	10	M	0.59
VI	29	11	F	0.70
VI	22	11	F	0.83
VI	28	11	M	0.73

Table 6.1.5. Strontium-90 in vertebrae from adults (> 29 years) in 1978

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr $(g\ Ca)^{-1}$
I	40	2	F	0.98
II	82	1	M	0.74
II	61	1	F	1.05
II	56	3	M	0.40
III	34	1	M	0.85
III	49	1	M	0.99
III	73	1	F	1.47
IV	64	2	M	1.39
VI	38	11	F	0.84
VI	43	11	M	1.64
VI	32	11	M	0.80
VI	31	1	M	1.70

Table 6.1.6. Strontium-90 (pCi $(g\ Ca)^{-1}$) in human vertebrae collected in Denmark 1978

Age group	Number of samples	Number of analysis	Min.	Max.	Median	Mean
Infants (≤ 4 years)	11	6	0.58	1.23	0.76	0.81
Children (≤ 19 years)	8	8	0.65	1.59	0.94	1.00
Adults (≤ 29 years)	11	11	0.59	1.28	0.83	0.86
Adults (≥ 30 years)	12	12	0.40	1.70	0.98	1.07

The levels were similar to those in 1977. The levels in the different age groups were not much different. The observed mean concentration in adults (≥ 30 years) was approx. 90% of that predicted (cf. Appendix C).

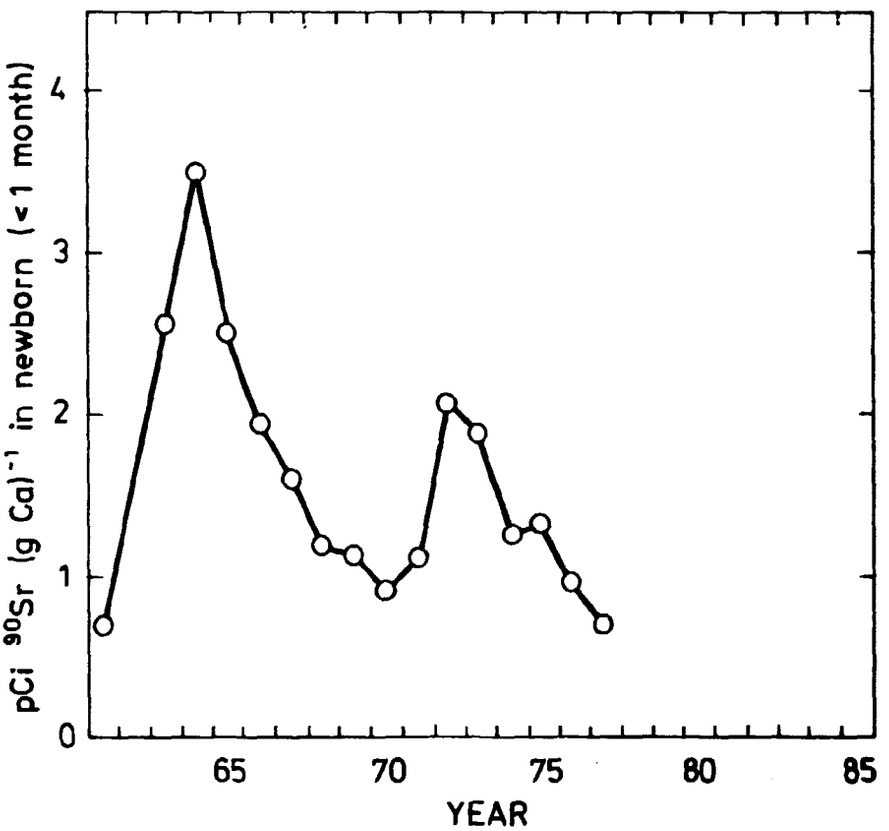

Fig. 6.1.1. Strontium-90 in bone from newborn 1961-1978.

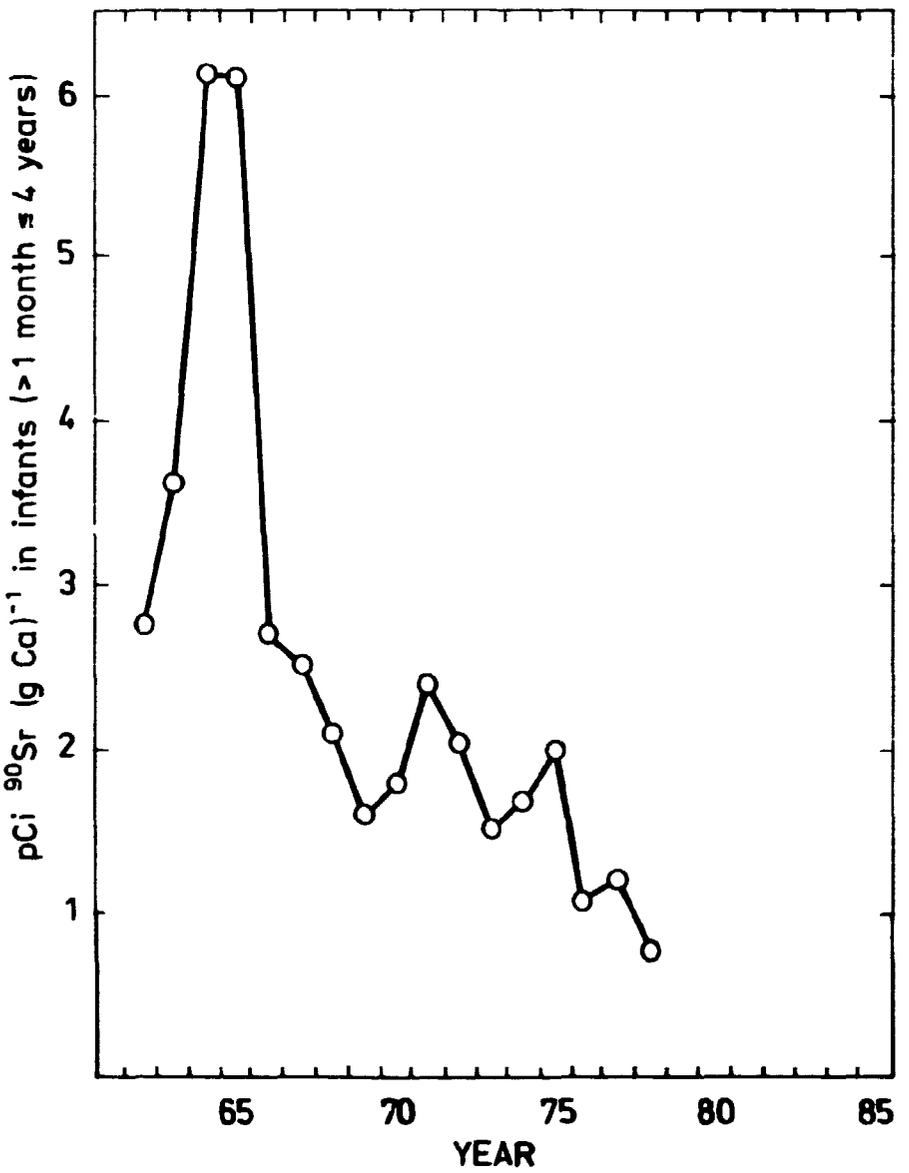

Fig. 6.1.2. Strontium-90 in bone from infants 1962-1978.

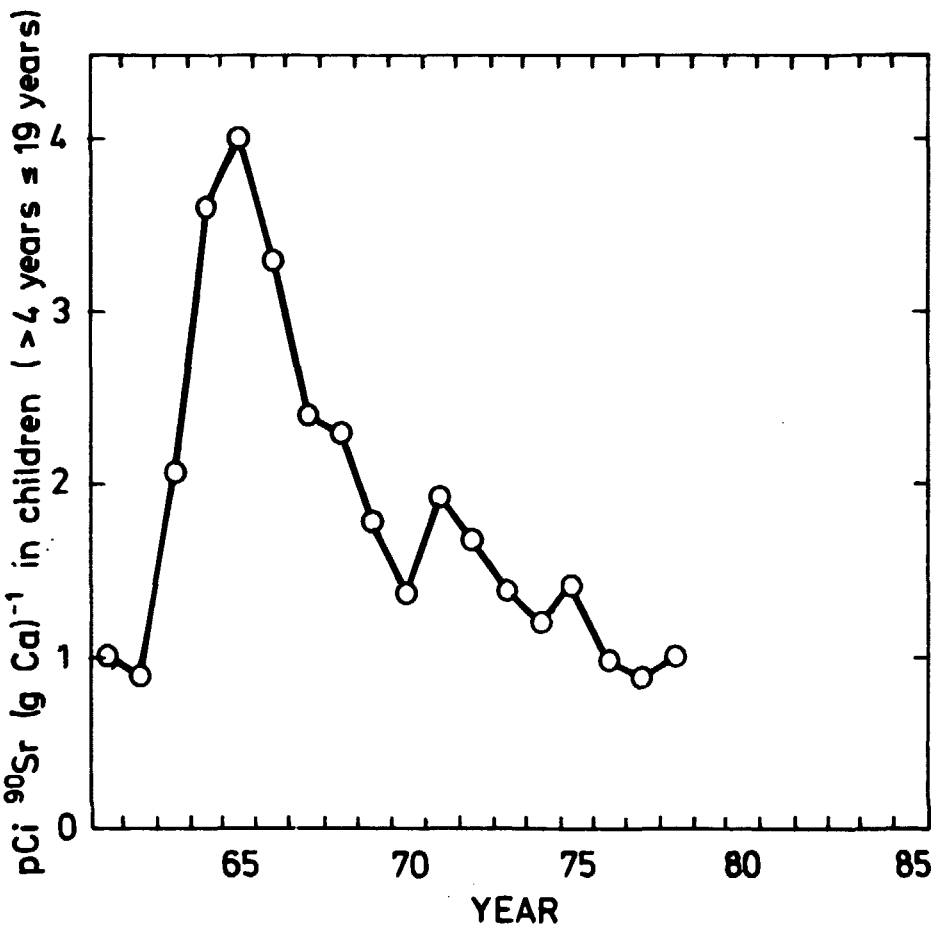

Fig. 6.1.3. Strontium-90 in bone from children 1961-1978.

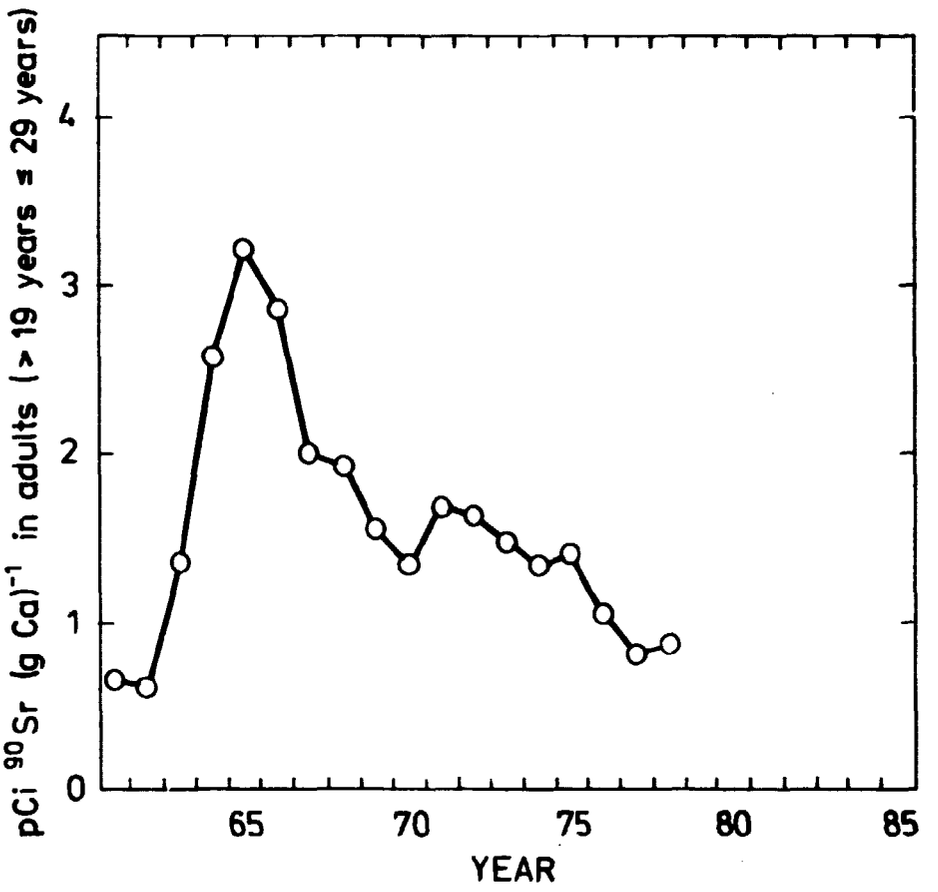

Fig. 6.1.4. Strontium-90 in vertebrae from adults ≤ 29 y, 1961-1978.

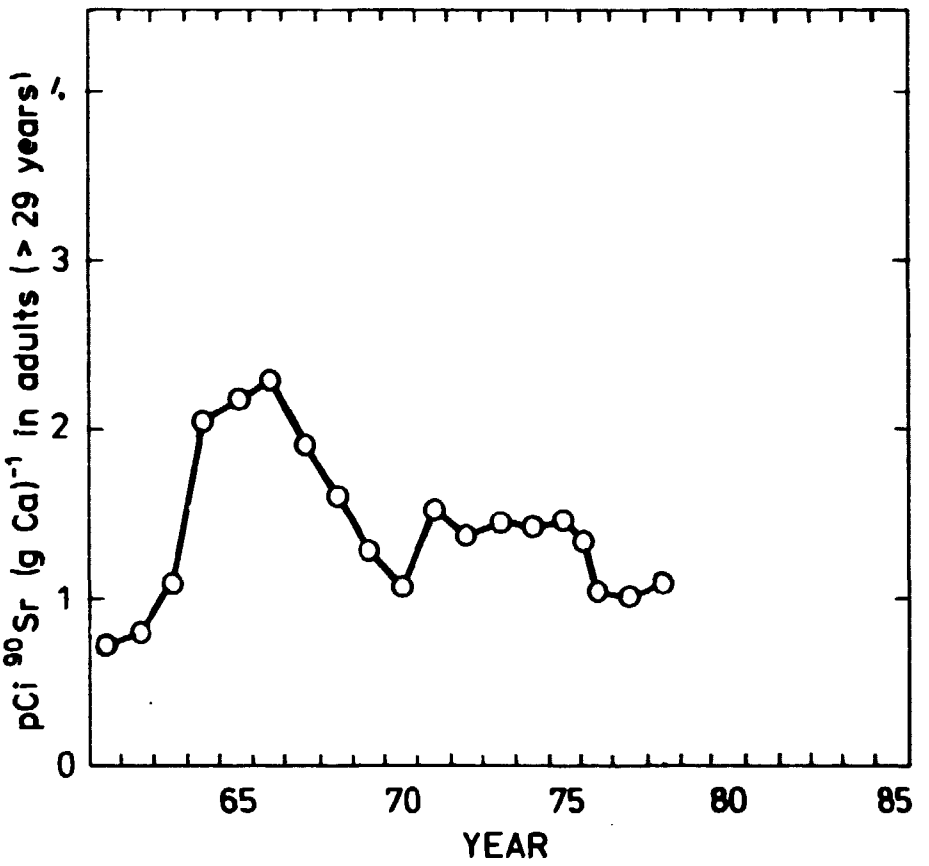

Fig. 6.1.5. Strontium-90 in vertebrae from adults > 29 y, 1961-1978.

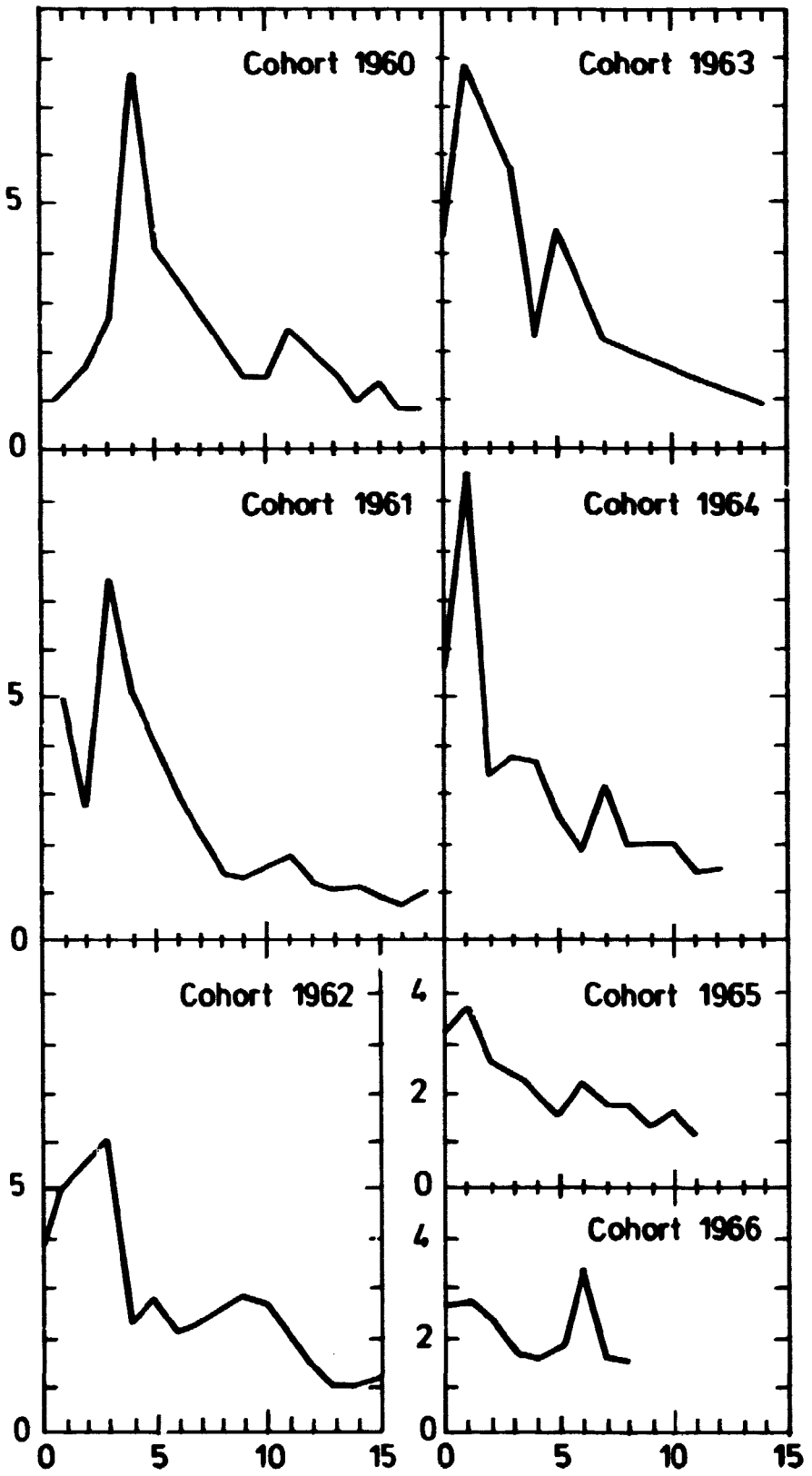

Fig. 6.1.6. Strontium-90 in human bone from Danish cohorts 1960-1966. (Abscissa: age in years. Ordinate: bone level in pCi ^{90}Sr (g Ca)$^{-1}$).

6.2. Cesium-137 in the human body

Whole-body measurements were initiated at Risø in July 1963 (cf. 2.3 in Risø Report No. 85[1]). A control group from the Health Physics Department was selected and has since then been measured as far as possible three times a year. Table 6.2 shows the results.

Due to the decreasing ^{137}Cs-content in the body, the contribution to the γ-spectra from ^{228}Ra daughter products becomes more interfering. Previous calculations were based on least squares fits to ^{137}Cs and ^{40}K standard spectra; an attempt to reduce the significance of the interference by including a spectrum from a source of ^{228}Ra + daughter products in the fit has resulted in an increase in the calculated values for ^{137}Cs while the calculated standard deviation for the individual measurements has improved.

The annual mean value of the control group was 16.7 pCi ^{137}Cs $(g\ K)^{-1}$. As earlier, we shall consider this figure representative of the mean of the Danish population in 1978. The total-body content of ^{137}Cs in 1978 for a standard man containing 140 g of potassium equals $140 \cdot 16.7 \cdot 10^{-3}$ nCi = 2.3 nCi ^{137}Cs, i.e. approx. 2 times the 1977 level. Total diet ^{137}Cs increased by a factor of 1.4 from 1977 to 1978. The higher increase for wholebody was ascribed to the new calculation method for the weak ^{137}Cs peek.

Figure 6.2 shows the mean M.U. values (with one S.E.) for men and women measured in 1963-1978.

The maximum was reached in August 1964. The mean level in the male group was approx. 1.3 times as high as that in the female group.

Table 6.1. Whole-body measurements of cesium-137 and potassium in 1978

Sex	Counting date	Age	Height in cm	Weight in kg	M.U. in body	pCi ^{137}Cs kg^{-1}	g K kg^{-1} body weight
M	April	46	193	78	16.3	39	2.39
M	"	45	172	70	12.6	29	2.30
M	"	21	178	68	11.1 B	33 B	2.96
M	"	21	172	65	13.4 A	32 A	2.39
M	"	30	169	70	14.9	39	2.62
F	"	36	167	55	11.5 A	24 A	2.60
M	"	27	177	64	24.6	59	2.60
F	"	38	163	63	15.4	33	2.14
F	"	38	160	54	15.5	34	2.19
F	"	40	164	78	12.5	20	1.60
F	"	49	171	66	20.4	42	2.86
F	"	34	158	44	11.2 A	32 A	2.87
M	"	40	174	80	18.3	42	2.29
M	"	54	183	72	31.6	95	2.69
F	"	52	154	90	11.6 A	17 A	1.47
F	"	49	157	64	12.7 A	20 A	2.21
M	"	35	174	72	16.2	43	2.66
M	"	47	192	89	19.3	44	2.28
M	September	46	193	78	15.1	33	2.18
M	"	45	172	70	12.8	28	2.33
M	"	21	178	59	13.4	43	3.22
M	"	30	188	75	16.8	42	2.62
M	"	21	172	65	14.4	33	2.29
M	"	30	169	70	18.8	49	2.72
F	"	36	167	56	11.5 A	24 A	2.09
M	"	20	177	65	41.7*	93*	2.23
F	"	23	169	49	8.7 A	21 A	2.42
F	"	43	158	63	10.2	21	2.05
M	"	26	178	64	16.7	40	2.87
M	"	46	184	66	16.6	48	2.89
M	"	60	167	78	15.8 A	31 A	2.06
F	"	38	163	65	13.4	23	1.71
F	"	39	160	55	16.7	32	2.17
F	"	25	158	58	19.2	41	2.13
M	"	39	178	77	13.2	30	2.27
F	"	50	171	65	14.0	30	2.14
F	"	35	158	44	13.7	39	2.84
M	"	55	183	71	29.4	84	2.86
F	"	52	154	94	73.4*	94*	1.28
M	"	26	180	60	16.2	43	2.65
F	"	49	157	65	12.5 A	24 A	1.92
M	"	38	181	73	19.3	47	2.44
M	"	35	174	72	14.1	40	2.84
M	December	46	193	78	27.1	56	2.05
F	"	41	173	60	20.6 A	49 A	2.38
M	"	46	172	70	16.5	38	2.30
M	"	22	170	59	14.7	50	3.39
M	"	30	180	76	17.4	44	2.53
M	"	22	172	73	20.3	47	2.32
M	"	30	169	71	19.4	50	2.58
M	"	28	177	63	36.9*	86*	2.33
F	"	23	169	51	13.4	32	2.38
M	"	57	185	106	22.2	39	1.76
F	"	44	158	63	14.7	32	2.18
M	"	47	170	74	22.8	52	2.26
M	"	47	184	66	22.2	55	2.48
M	"	61	167	70	13.0	33	2.53
F	"	41	164	58	19.6	40	2.04
M	"	31	190	83	16.0	38	2.38
F	"	50	171	67	19.4	43	2.22
F	"	35	158	44	17.7	50	2.82
M	"	40	174	78	19.3	43	2.23
M	"	55	183	73	22.4	64	2.86
F	"	52	154	94	63.5*	94*	1.48
M	"	26	180	60	22.5	59	2.62
M	"	36	174	73	19.9	47	2.36

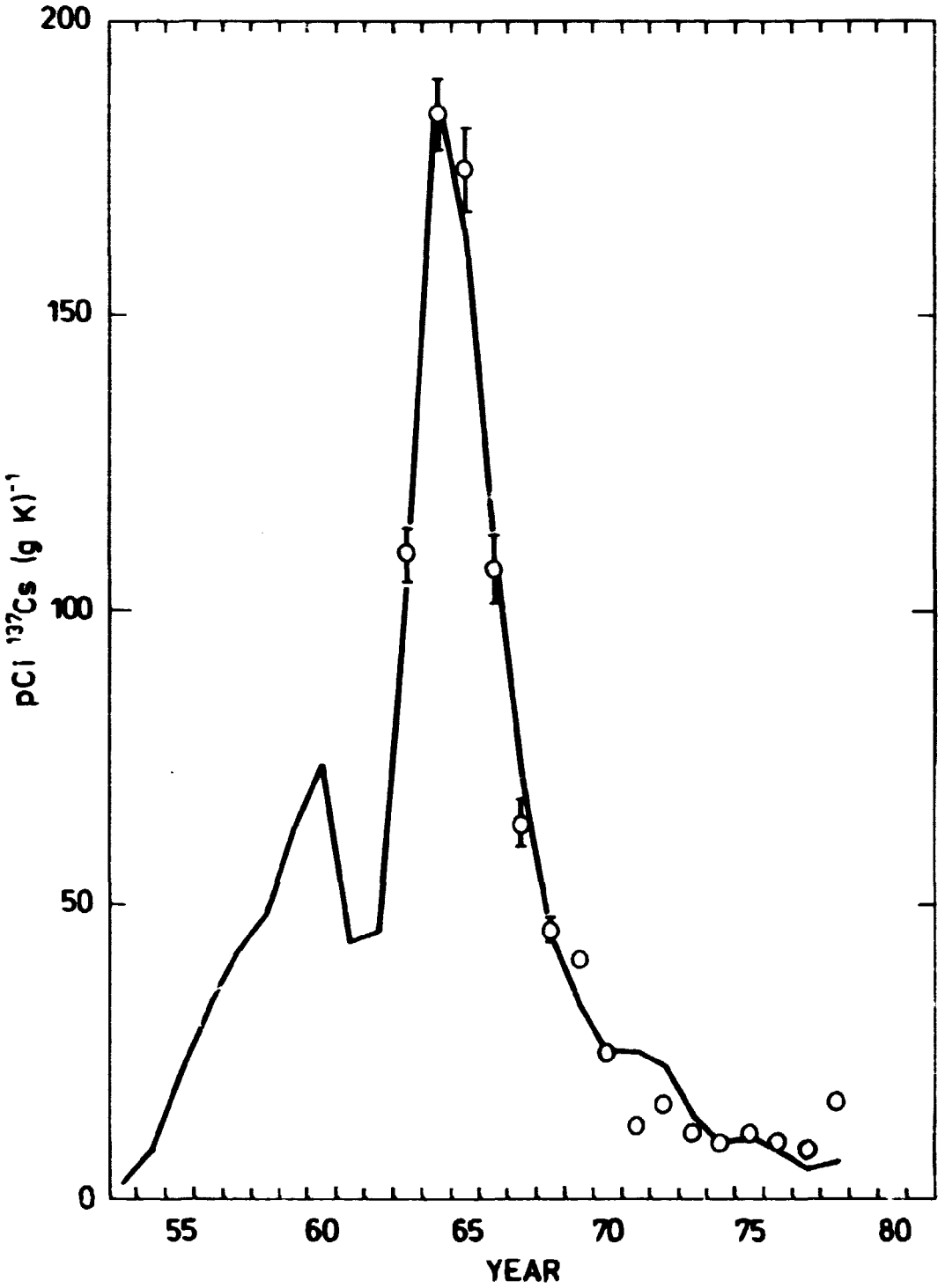

Fig. 6.2. A comparison between observed (± 1 SE) and calculated (curve, cf. Appendix C) pCi ^{137}Cs (g K)$^{-1}$ levels in whole-body from the Islands.

7. TRITIUM IN THE ENVIRONMENT

by Heinz Hansen

7.1. Introduction

Tritium is produced naturally in the atmosphere by the interaction of cosmic-ray protons and neutrons with nitrogen, oxygen or argon. Surface waters contain about 0.01 nCi/l from this source[25]. Tritium is also produced and injected into the stratosphere as the result of thermonuclear explosions. At present, this latter source has enhanced the natural inventory by about a factor of ten[25]. Finally, tritium is produced as a by-product of the peaceful uses of atomic energy: it is released both during reactor operation and during fuel reprocessing.

Before Denmark builds any nuclear power stations of her own, it is of interest to know the general tritium levels in the environment that could be affected by this new energy source. Also, an assay of the current tritium levels can be used to control any tritium release from the Swedish nuclear power stations at Barsebäck and Ringhals, and from the reprocessing plants at Windscale and La Hague.

7.2. Assay of tritium in low-level amounts

The present assays of tritium levels in water are based on a relative enrichment of ^3H_2O by electrolysis and subsequent liquid scintillation counting as previously described [1] (Risø report no. 386) with two further comments:

1) Electrolysis was stopped at a current of 1.0 amps by separate automatic switches for each cell, instead of by itself, as was done previously, when electrolysis had reduced the liquid level below the anode level. This was a major advantage in connection with the reproducibility of the results.

2) Separate runs with stainless steel cathodes instead of iron ones showed an average $^{3}H_2O$ recovery of 44% compared with the normal value 75%. Even though stainless steel cathodes are easier to clean, they cannot be recommended.

7.3. Results

The amount of globally available tritium by 1978 was estimated at 2700 MCi and the total tritium production by nuclear weapons testing was estimated at 4750 MCi[25].

The ratio of ^{3}H to ^{90}Sr in undecayed global fallout was estimated at 300[25], and in the cumulative deposition the ratio was 240.

In 1978 this ratio in precipitation collected in Denmark was 388 (mCi ^{3}H km^{-2} at Risø/mCi ^{90}Sr km^{-2} total country); in 1977 it was 385. Hence the rain in 1978 (and 1977) showed higher tritium levels than expected from the ^{90}Sr concentration and the above ratios.

Table 7.3.1. Tritium in precipitation collected at Risø in 1978

Month	mm	nCi ^{3}H l^{-1}	mCi ^{3}H km^{-2}
Jan	53	0.42±0.08*	22.3
Feb	10	0.31±0.01	3.1
March	48	0.21±0.05	10.1
April	4	0.32±0.07	1.28
May	9	0.36±0.01	3.2
June	47	1.29±0.05	60.6
July	55	0.28±0.01	15.4
Aug	86	0.25±0.01	21.5
Sept	126	0.24±0.03	30.2
Oct	34	0.12±0.00	4.1
Nov	23	0.17±0.01	3.9
Dec	32	0.15±0.01	4.8
1978	Σ 527	$\bar{x}$ 0.34	Σ 180

* Triple determination.

The error term was ±1 SE.

Table 7.3.2. Tritium in ground water collected in March 1978

Location	nCi $^{3}H\ l^{-1}$
Hvidsten	0.05±0.01
Feldbak	0.30±0.05
Rømø	0.16±0.03
Rønne New*	0.11±0.04 Δ
Rønne Old*	0.15±0.01
Hasselø	0.30±0.01
Fåretofte	0.38±0.06
Kalundborg	0.24±0.03 Δ
Ravnholt	0.41±0.01
Fredericia	0.32±0.03
Mean	0.24
Median	0.27

A sample of ground water from Maglekilde in Roskilde contained 0.33±0.01 nCi l^{-1}.
The error term was ±1 SE.
* Collected in June.
Δ Triple determination.

Table 7.3.3. Tritium in Danish streams and lakes in March 1977. (Unit: nCi $^{3}H\ l^{-1}$. ±1 SE)

Zone		Streams		Lakes	
I:	North Jutland	Bangsbo å	0.34±0.04	Norsø	0.76±0.02
II:	East Jutland	Guden å	0.46±0.02	Mosø	0.30±0.02
III:	West Jutland	Skjern å	0.30±0.03	Flyndersø	0.41±0.01
IV:	South Jutland	Ribe å	0.34±0.01	Hostrup sø	0.36±0.03
V:	Funen	Odense å	0.74±0.08	Arreskov sø	0.75±0.12
VI:	Zealand	Susåå	0.42±0.02	Arresø	0.34±0.04
VII:	Lolland-Falster	Halsted å	0.42±0.10	Søndersø	0.46±0.04
VIII:	Bornholm	Læså	0.34±0.08	Almindingen sø	0.60±0.04
Mean			0.42		0.50

Table 7.3.4. Tritium in sea water collected in 1978

Location	Position or station number N	E	Depth in m	Date	^3H nCi l^{-1} ±1 SE	Salinity o/oo
Kullen	56°15'	12°25'	0	June	0.38±0.04	16.6
- " -	- " -	- " -	21	"	0.16±0.06	35.7
Hesselø	56°10'	11°47'	0	"	0.73±0.12*	20.7
- " -	- " -	- " -	24	"	0.20±0.01	33.5
Kattegat M	56°07'	11°10'	0	"	0.47±0.02	16.7
- " -	- " -	- " -	35	"	0.50±0.10	35.6
Asnæs rev	55°38'	10°47'	0	"	0.59±0.13Δ	13.2
- " -	- " -	- " -	40	"	0.23±0.05	34.2
Halskov rev	55°20'	11°02'	0	"	0.36±0.08	12.8
- " -	- " -	- " -	34	"	0.34±0.00	34.2
Langeland belt	54°52'	10°50'	0	"	0.32±0.04	13.9
- " -	- " -	- " -	47	"	0.36±0.02	33.2
Femern belt	54°36'	11°05'	0	"	0.56±0.04	18.4
- " -	- " -	- " -	25	"	0.16±0.01	30.7
Gedser rev	54°28'	12°13'	0	"	0.44±0.06	18.1
- " -	- " -	- " -	23	"	0.20±0.00	24.4
Møn	54°57'	12°41'	0	"	0.38±0.08	9.0
- " -	- " -	- " -	20	"	0.22±0.02	18.1
The Sound-South	55°25'	12°39'	0	"	0.54±0.06*	9.0
- " -	- " -	- " -	12	"	0.26±0.08	20.1
The Sound-North A	55°48'	12°44'	0	"	0.42±0.00	9.0
- " -	- " -	- " -	19	"	0.40±0.00	25.7
The Sound-North B	55°59'	12°42'	0	"	0.30±0.04	9.0
- " -	- " -	- " -	24	"	0.22±0.04Δ	34.0
Barsebäck **	34		0	April	0.30±0.06	10.3
- " -	19		0	"	0.18±0.00*	10.4
- " -	34		0	June	0.34±0.08	10.3
- " -	34		15	"	0.24±0.05Δ	25.6
Ringhals ***	57°14'	11°53'7	66	May	0.14±0.02	34.2
- " -	1		27	"	0.19±0.01	36.0
- " -	2		0	"	0.22±0.02	18.0
- " -	2		22	"	0.21±0.01	36.0
- " -	3		0	"	0.24±0.04	19.5
- " -	3		18	"	0.18±0.04	32.8
- " -	15		0	"	0.27±0.01	19.4
- " -	15		10	"	0.16±0.02Δ	27.8
The North Sea	55°40'2	07°05'0	0	15/9	0.15±0.06Δ	35.4
- " -	55°26'5	05°34'0	0	15/9	0.16±0.04*	35.2
- " -	58°13'	02°42'	0	4/11	0.12±0.05*	35.6
- " -	57°50'	05°27'	0	5/11	0.09±0.01Δ	35.6
- " -	57°40'	08°02'	0	5/11	0.12	32.9

* 4 determinations

Δ 3 - " -

**(cf. Fig. 3.2.1.)

***(cf. Fig. 3.2.2.)

Table 7.3.5 shows that lake water and stream water and especially ground water yielded higher $^{3}H/^{90}Sr$ ratios than precipitation; this is due to the sorption of ^{90}Sr from water in contact with soil minerals. The sea water ratios were somewhat higher than those in precipitation.

Table 7.3.5. The mean ratio of pCi $^{3}H\ l^{-1}$/pCi $^{90}Sr\ l^{-1}$ (±1 SD) in samples collected from various Danish waters in 1977 and 1978

		Number of samples	Reference
Lake water	1000±870	8	table 7.3.3 and table 4.3.2 in Risø Report No. 386
Stream water	1300±500	8	
Ground water	44000±37000	10	tables 7.3.2 and 4.3.1 (except Feldbak)
Sea water	517±123	7	tables 7.3.4 and 4.4.1

8. TRANSURANICS IN ENVIRONMENTAL SAMPLES

by Karen Nilsson

8.1. Soil samples

The soil samples collected in 1978 at St. Jyndevad (cf. 4.5) were analysed for $^{239,240}Pu$ and ^{241}Am. Table 8.1 shows the results. Anova's showed that there was no significant difference between the two graves A and B. They showed a similar vertical distribution of $^{239,240}Pu$ as that of ^{137}Cs. However, a closer inspection of data revealed a slightly decreasing $^{137}Cs/^{239,240}Pu$ ratio with depth, which may be an indication of $^{239,240}Pu$ being more mobile than ^{137}Cs in the soil column.

As compared with the corresponding investigation at Skydebanen in 1977 (cf. Risø Report No. 386[1]), St. Jyndevad showed a more slowly decreasing ratio of $^{137}Cs/^{239,240}Pu$ than Skydebanen, the half depths being approximately 150 and 40 cm respectively. The pronounced difference in soil types at the two locations may explain the difference (cf. 4.5).

Americium-241 was detectable in a few soil samples. The concentrations were approximately one-third of those of $^{239,240}Pu$, which is the ratio usually found in accumulated fallout. The total deposits at St. Jyndevad in 1978 was estimated at 1.9 mCi $^{239,240}Pu\ km^{-2}$ and 0.6 mCi $^{241}Am\ km^{-2}$.

Table 8.1. Plutonium and americium in soil samples collected in June 1978 at St. Jyndevad

Depth cm	A_1		A_2		B_1		B_2	
	pCi $^{239,240}Pu$ kg^{-1}	mCi $^{239,240}Pu$ km^{-2} cm^{-1}	pCi $^{239,240}Pu$ kg^{-1}	mCi $^{239,240}Pu$ km^{-2} cm^{-1}	pCi $^{239,240}Pu$ kg^{-1}	mCi $^{239,240}Pu$ km^{-2} cm^{-1}	pCi $^{239,240}Pu$ kg^{-1}	mCi $^{239,240}Pu$ km^{-2} cm^{-1}
2.5	4.93	0.065	3.85 (1.13)	0.045	4.86 (1.51)	0.067	-	-
5	4.68	0.108	4.01 (0.92)	0.078	3.62 (1.53)	0.072	-	-
10	3.88	0.065	3.73 (1.47)	0.072	3.91 (1.18)	0.072	3.39(1.21)	0.066
15	4.54	0.083	4.10 (1.07)	0.080	2.86	0.057	-	-
20	4.20	0.089	3.59 (1.40)	0.067	1.25	0.028	2.20	0.042
25	2.35	0.048	2.29	0.041	1.53	0.030	-	-
30	0.04 B	0.0007 B	0.66	0.0147	B.D.L.	B.D.L.	B.D.L.	B.D.L.
40	-	-	-	-	B.D.L.	B.D.L.	-	-
50	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-
100	-	-	-	-	-	-	-	-

The figures in brackets are pCi ^{241}Am kg^{-1}. The mean ratio ^{241}Am /$^{239,240}Pu$ was 0.33 ± 0.07 (1 SD)

8.2. Plutonium in various marine samples collected at Ringhals

Sediments collected at location 1 (cf. Fig. 3.2.1.2) in May contained 0.66 mCi ^{239,240}Pu km^{-2} (0-12 cm). At location 3 the Pu-level was 0.51 mCi km^{-2} (0-15 cm) in May and 1.03 mCi km^{-2} in September. These levels are similar to those measured previously (Risø Reports Nos. 361 and 386[1]).

Tables 8.3 and 8.4 show the ^{239,240}Pu contents of Fucus sp. and Mytilus. The levels were similar to those obtained earlier.

Table 8.2. Plutonium in sediment samples collected at Ringhals in 1978

Date	Position (cf. Fig. 3.2.2.)	Depth in cm	pCi ^{239,240}Pu kg^{-1}	mCi ^{239,240}Pu km^{-2}	pCi ^{238}Pu kg^{-1}	mCi ^{238}Pu km^{-2}
May 21	1	0-3	13.37	0.25	0.84 A	0.016 A
- " -	1	3-6	11.95	0.30	0.16 B	0.004 B
- " -	1	6-9	2.96	0.095	0.20 A	0.006 A
- " -	1	9-12	0.32 A	0.010	B.D.L.	B.D.L.
May 21	3	0-3	11.11	0.26	B.D.L.	B.D.L.
- " -	3	3-6	5.26	0.160	B.D.L.	B.D.L.
- " -	3	6-9	2.10	0.056	B.D.L.	B.D.L.
- " -	3	9-12	0.80	0.027	B.D.L.	B.D.L.
- " -	3	12-15	0.59	0.010	B.D.L.	B.D.L.
Sept 4	1	0-3	4.12	0.130	B.D.L.	B.D.L.
- " -	1	3-6	B.D.L.	B.D.L.	B.D.L.	B.D.L.
- " -	1	6-9	B.D.L.	B.D.L.	B.D.L.	B.D.L.
- " -	1	9-12	B.D.L.	B.D.L.	B.D.L.	B.D.L.
Sept 4	3	0-3	13.31	0.41	B.D.L.	B.D.L.
- " -	3	3-6	12.19	0.47	B.D.L.	B.D.L.
- " -	3	6-9	1.14	0.046	B.D.L.	B.D.L.
- " -	3	9-13	1.61	0.104	B.D.L.	B.D.L.

Table 8.3. Plutonium in sea weed collected at Ringhals May 20, 1978

Type	Position	pCi $^{239,240}Pu\ kg^{-1}$
Fucus vesiculosus	5	10.0
- " -	8	10.8
Fucus serratus	7	15.9

Table 8.4. Plutonium in Mytilus edulis (flesh) collected at Ringhals May 20, 1978

Position	pCi $^{239,240}Pu\ kg^{-1}$
5	6.6
7	3.1
8	2.4

9. MEASUREMENTS OF BACKGROUND RADIATION IN 1978

by L. Bøtter-Jensen and S.P. Nielsen

9.1. Instrumentation

Measurements of the background radiation were made using thermoluminiscence dosimeters (TLD's)[23], a mobile Ge(Li) spectrometer system[24], a high pressure ionization chamber and a Na(Tl) detector. These instruments have been subject to a systematic intercomparison[31], which has resulted in corrections being applied to the results from the ionization chamber and NaI(Tl) detector. The results of measurements from previous years made with these instruments are therefore not directly comparable to those from this year.

9.2. State experimental farms

The State experimental farms are situated as shown in fig. 4.2. The results of the TLD measurements are shown in table 9.2.1. The results from a special supplementary measurement programme during April to September 1978 are included. The results of the Ge(Li) spectrometer measurements are shown in tables 9.2.2-9.2.5. Tables 9.2.2 and 9.3.3 show terrestrial exposure rates, and tables 9.2.4 and 9.2.5 show radionuclide concentrations in the soil. Results of measurements made with the ionization chamber are presented in table 9.2.6, and table 9.2.7 shows the results from the NaI(Tl) detector.

Estimates of the intensity of the secondary cosmic radiation at sea level were obtained as the difference between the ionization chamber results in table 9.2.6 and the Ge(Li) spectrometer results in table 9.2.2 and 9.2.3. The detailed analysis of these data is reported elsewhere[31]. An average value for the secondary cosmic radiation of 3.6 $\mu R\ h^{-1}$ was obtained, which is in agreement with the value adopted by UNSCEAR[25].

Table 9.2.1. TLD-measurements of the background radiation (μR h^{-1}) at the state experimental farms in 1978

	Winter 1977-1978	Summer 1978	Supplement Summer 1978*	Mean
Tylstrup	7.5	7.6	7.5	7.5
Studsgård	6.9	6.8	6.5	6.7
Ødum	8.5	8.6	8.5	8.5
Askov	7.6	7.9	7.5	7.7
St. Jyndevad	6.2	6.1	5.9	6.1
Blangstedgård	8.0	8.1	8.7	8.3
Tystofte	8.4	8.5	8.2	8.4
Abed	8.0	7.9	9.1	8.3
Mean	7.6	7.7	7.7	7.7

*ref. 31

Table 9.2.2. Terrestrial exposure rates at the State experimental farms estimated from field spectroscopic measurements made in June 1978 (μR h^{-1})

Location	^{40}K	^{226}Ra	^{232}Th	^{137}Cs	Total
Tylstrup	2.1	0.6	0.9	0.1	3.8
Studsgård	0.8	0.4	0.6	0.9	2.7
Ødum	2.2	0.7	1.1	0.1	4.1
Askov	1.5	0.7	1.0	0.2	3.3
St. Jyndevad	1.0	0.4	0.3	0.1	1.8
Blangstedgård	2.3	0.9	1.4	0.1	4.8
Ladreborg	2.4	1.0	1.5	0.1	5.0
Tystofte	2.2	1.6	1.3	0.1	5.2
Abed	2.3	1.0	1.7	0.1	5.2
Tornbygård*	2.6	1.1	1.8	0.1	5.6
Mean	1.9	0.8	1.2	0.2	4.2

*Bornholm

Table 9.2.3. Terrestrial exposure rates at the State experimental farms estimated from field spectroscopic measurements made in September 1978 ($\mu R\ h^{-1}$)

Location	^{40}K	^{226}Ra	^{232}Th	^{137}Cs	Total
Tylstrup	1.7	1.0	0.6	0.1	3.4
Studsgård	0.6	0.4	0.5	0.7	2.2
Ødum	2.1	1.0	1.1	0.1	4.2
Askov	1.3	0.8	0.9	0.2	3.1
St. Jyndevad	1.0	0.6	0.3	0.1	2.0
Blangstedgård	2.2	0.8	1.3	0.1	4.4
Ledreborg	2.3	0.9	1.4	0.1	4.7
Tystofte	2.2	0.9	1.3	0.1	4.5
Abed	2.3	1.1	1.6	0.1	5.1
Tornbygård*	2.4	1.0	1.6	0.1	5.2
Mean	1.8	0.9	1.1	0.2	3.9

*Bornholm

Table 9.2.4. Radionuclides in the soil at the State experimental farms estimated from field spectrometric measurements made in June 1978 ($pCi\ g^{-1}$)

Nuclide	Tylstrup	Studs-gård	Ødum	Askov	Jyndevad	Blangsted-gård	Ledre-borg	Tystofte	Abed	Tornby-gård*	Mean
^{40}K	11.7	4.3	12.1	7.9	5.5	12.7	13.0	12.0	12.7	14.3	10.6
^{226}Ra	0.29	0.21	0.35	0.36	0.18	0.47	0.55	0.84	0.53	0.55	0.43
^{232}Th	0.34	0.22	0.40	0.35	0.10	0.51	0.53	0.47	0.62	0.63	0.42
^{137}Cs**	0.21	-	0.22	0.26	0.23	0.21	0.15	0.17	0.18	0.23	0.21

* Bornholm

**Assuming a homogeneous distribution 0-20 cm.

Table 9.2.5. Radionuclides in the soil at the State experimental farms estimated from field spectrometric measurements made in September 1978 ($pCi\ g^{-1}$)

Nuclide	Tylstrup	Studs-gård	Ødum	Askov	Jyndevad	Blangsted-gård	Ledre-borg	Tystofte	Abed	Tornby-gård*	Mean
^{40}K	9.2	3.4	11.3	6.8	5.3	11.9	12.5	12.1	12.4	13.2	9.8
^{226}Ra	0.51	0.20	0.51	0.45	0.33	0.43	0.49	0.45	0.58	0.53	0.45
^{232}Th	0.23	0.18	0.38	0.31	0.10	0.47	0.52	0.48	0.58	0.59	0.38
^{137}Cs**	0.18	-	0.22	0.24	0.23	0.18	0.16	0.20	0.20	0.19	0.20

* Bornholm

**Assuming a homogeneous distribution 0-20 cm.

Table 9.2.6. Ionization chamber measurements of the background radiation at the State experimental farms in 1978 ($\mu R\ h^{-1}$)

Location	April	June	September	Mean
Tylstrup	7.0	7.2	7.3	7.2
Studsgård	6.0	6.3	6.0	6.1
Ødum	7.5	7.8	8.1	7.8
Askov	6.9	7.1	7.1	7.0
St. Jyndevad	5.5	5.5	5.6	5.5
Blangstedgård	7.9	8.2	8.0	8.0
Ledreborg	8.4	8.5	8.4	8.4
Tystofte	8.1	8.6	8.0	8.2
Abed	8.3	8.7	8.7	8.6
Tornbygård*		9.2	9.0	9.1
Mean	7.5	7.7	7.6	7.6

*Bornholm

Table 9.2.7. Terrestrial exposure rates at the State experimental farms in 1978 measured with the NaI(Tl) detector ($\mu R\ h^{-1}$)

Location	April	June	Sept	Nov	Dec	Mean
Tylstrup	3.7	3.4	3.3	3.7	3.6	3.6
Studsgård	2.7	2.7	2.4	3.1	3.2	2.8
Ødum	3.9	4.3	4.3	4.5	4.6	4.3
Askov	3.4	3.4	3.7	3.7	3.7	3.6
St. Jyndevad	2.4	1.6	1.7	2.2	2.3	2.0
Blangstedgård	4.7	5.9	4.0	4.7	4.7	4.8
Ledreborg	5.5	4.6	4.9	5.0	5.0	5.0
Tystofte	5.3	4.7	4.3	5.0	5.3	4.9
Abed	5.7	5.0	5.3	5.7	5.5	5.4
Tornbygård*		5.8	5.4			5.6
Mean	4.1	4.1	3.9	4.2	4.2	4.2

*Bornholm

9.3. Risø environment

The five zones around Risø are located as shown in fig. 9.3.1 and the results of the NaI(Tl) detector measurements are shown in table 9.3.2.

In the Risø environment a few Ge(Li) spectroscopic measurements were made in zone I. The only artificial radioisotopes detected here were fallout ^{137}Cs and ^{41}A. The latter originates from routine operation of the reactor DR 3.

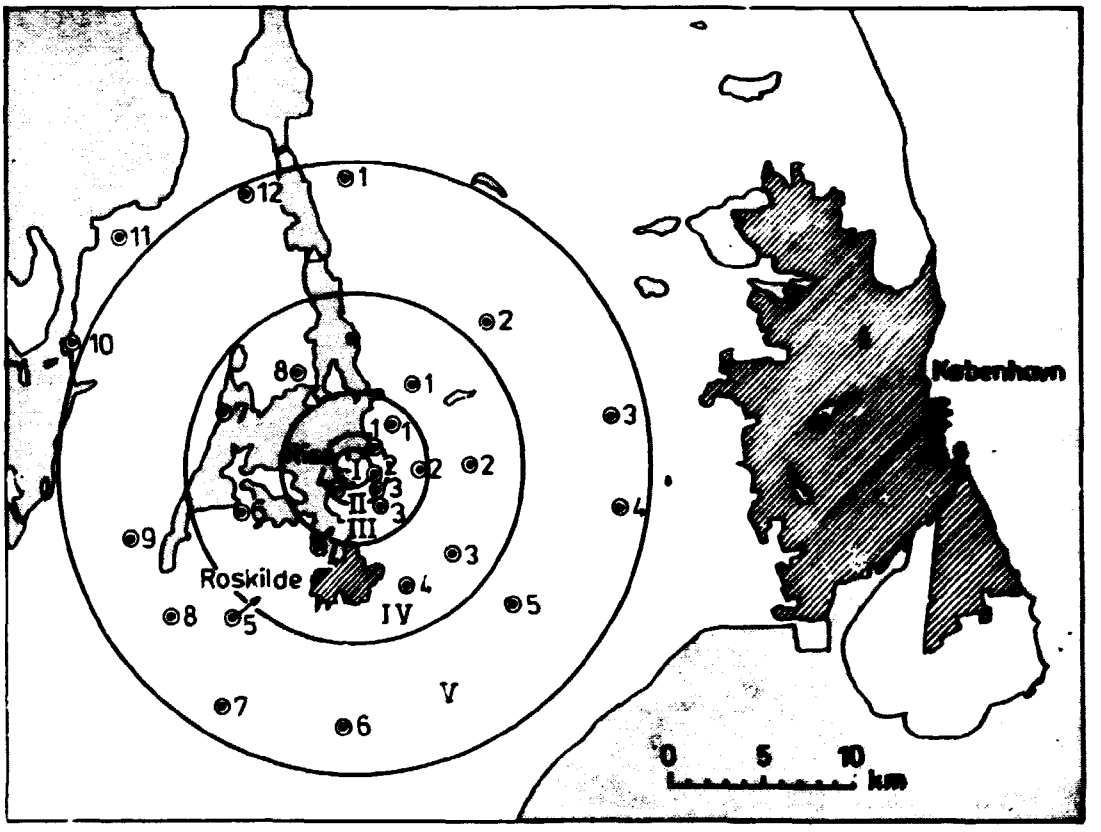

Fig. 9.3.1. The environment of Risø. Locations for measurements of the background radiation.

Table 9.3.1. TLD-measurements of the background radiation (μR h^{-1}) in five zones (I-V) around Risø in 1978

Risø zone	Location	Winter 1977-1978	Summer 1978	Mean
I	1	8.1	8.4	8.3
"	2	8.7	8.9	8.8
"	3	27.3	25.7	26.5
"	4	10.0	9.9	10.0
"	5	15.1	15.8	15.5
Mean		13.8	13.7	13.8
II	1	8.5	8.3	8.4
"	2	8.4	8.6	8.5
"	3	8.1	8.1	8.1
"	4	8.6	8.4	8.5
Mean		8.4	8.4	8.4
III	1	9.3	9.1	9.2
"	2	8.3	8.6	8.5
"	3	9.1	-	9.1
Mean		8.9	8.9	8.9
IV	1	8.6	7.8	8.2
"	2	8.7	8.5	8.6
"	3	8.8	8.4	8.6
"	4	9.3	8.9	9.1
"	5	7.0	6.7	6.9
"	6	9.2	8.7	9.0
"	7	9.6	9.0	9.3
Mean		8.7	8.3	8.5
V	1	8.5	8.4	8.5
"	2	9.9	9.3	9.6
"	3	8.7	8.2	8.5
"	4	8.7	8.2	8.5
"	5	9.8	9.0	9.4
"	6	9.0	9.0	9.0
"	7	9.6	8.2	8.9
"	8	7.9	7.6	7.8
"	9	-	8.8	8.8
"	10	8.8	8.7	8.8
Mean		9.0	8.5	8.8

Table 9.3.2. Terrestrial exposure rates at the Risø zones in 1978 measured with the NaI(Tl) detector ($\mu R\ h^{-1}$)

Risø zone	Location	May	June	Aug	Sept	Oct	Nov	Dec	Mean
I	1	5.5	5.0	5.4	5.0	4.8	5.1	5.3	5.2
"	2	6.2	6.9		6.6	6.8	6.8	6.4	6.6
"	3	87.4	73.1	68.4	85.9	83.4	87.4	73.8	79.9
"	4	5.7	6.0	5.1	5.3	5.7	6.0	5.8	5.7
"	5	16.2	16.4	18.4	18.2	15.9	16.0	18.2	17.0
Mean		24.2	21.5	24.3	24.2	23.3	24.3	21.9	23.4
II	1		4.6	4.6		4.7		5.0	4.7
"	2		5.4	5.2		5.8		5.3	5.4
"	3		4.7	3.5		3.9		4.0	4.0
"	4		4.6	3.9		4.5		5.0	4.5
Mean			4.8	4.3		4.7		4.8	4.7
III	1		5.8	5.0		5.5		5.6	5.7
"	2		4.6	4.9		5.2		5.1	5.0
"	3		4.6	4.4		4.9		4.9	4.7
Mean			5.0	4.8		5.5		5.2	5.1
IV	1					4.1			4.1
"	2					5.2			5.2
"	3					5.1			5.1
"	4					4.4			4.4
"	5					3.4			3.4
"	6					4.3			4.3
"	7					4.5			4.5
Mean						4.4			4.4
V	1					5.1			5.1
"	2					5.1			5.1
"	3					3.6			3.6
"	4					5.3			5.3
"	5					4.9			4.9
"	6					5.0			5.0
"	7					4.7			4.7
"	8					5.2			5.2
"	9					4.8			4.8
"	10					3.8			3.8
Mean						4.8			4.8

9.4. Gyllingnæs environment

The Gyllingnæs environment (a potential nuclear power plant site) is routinely monitored with TLD's, and the results from three zones around the site are given in table 9.4.1. The locations are shown in fig. 9.4.1.

Table 9.4.1. TLD-measurements of the background radiation (μR h^{-1}) in four zones (I-IV) around the Gyllingnæs site in 1978

Gyllingnæs zone	Location	Winter 1977-1978	Summer 1978	Mean
I	1	7.6	7.4	7.5
"	2	-	7.3	7.3
"	3	8.4	8.6	8.5
"	4	7.1	7.4	7.3
Mean		7.7	7.7	7.7
II	1	8.9	8.6	8.8
"	2	8.6	8.7	8.7
Mean		8.8	8.7	8.8
III	1	7.7	7.2	7.5
"	2	8.1	7.9	8.0
"	3	8.5	8.7	8.6
"	4	6.4	6.4	6.4
"	5	8.3	8.6	8.5
Mean		7.8	7.8	7.8
IV	1	8.4	8.5	8.5
"	2	8.7	8.6	8.7
"	3	8.2	8.2	8.2
Mean		8.4	8.4	8.4

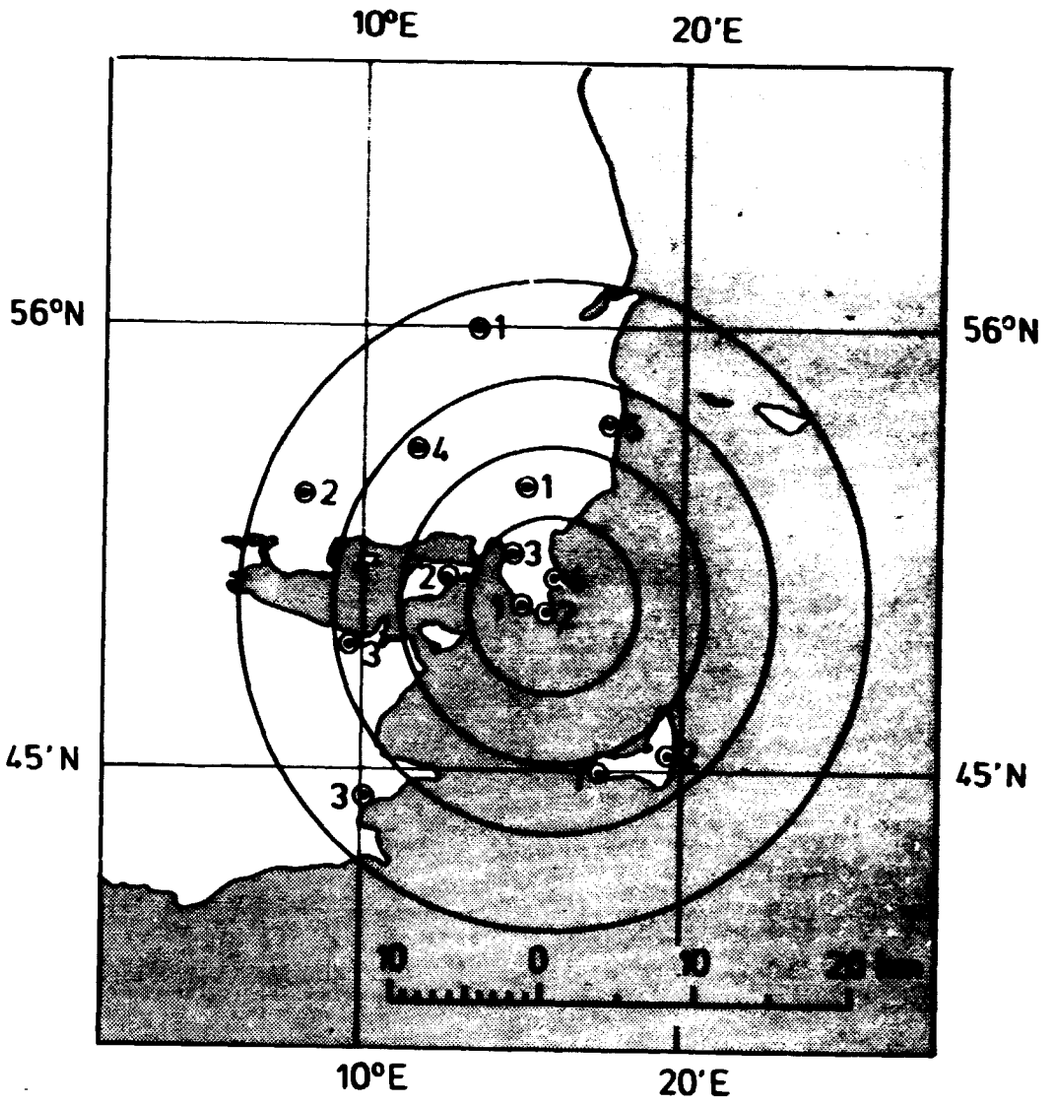

Fig. 9.4.1. The environment of Gyllingnæs. Locations for measurements of the background radiation.

9.5. Great Belt and Langeland Belt areas

Locations on both shores of the Great Belt and the Langeland Belt (an international shipping route) are likewise routinely monitored with TLD's; the results and locations are shown in table 9.5.1 and fig. 9.5.1, respectively.

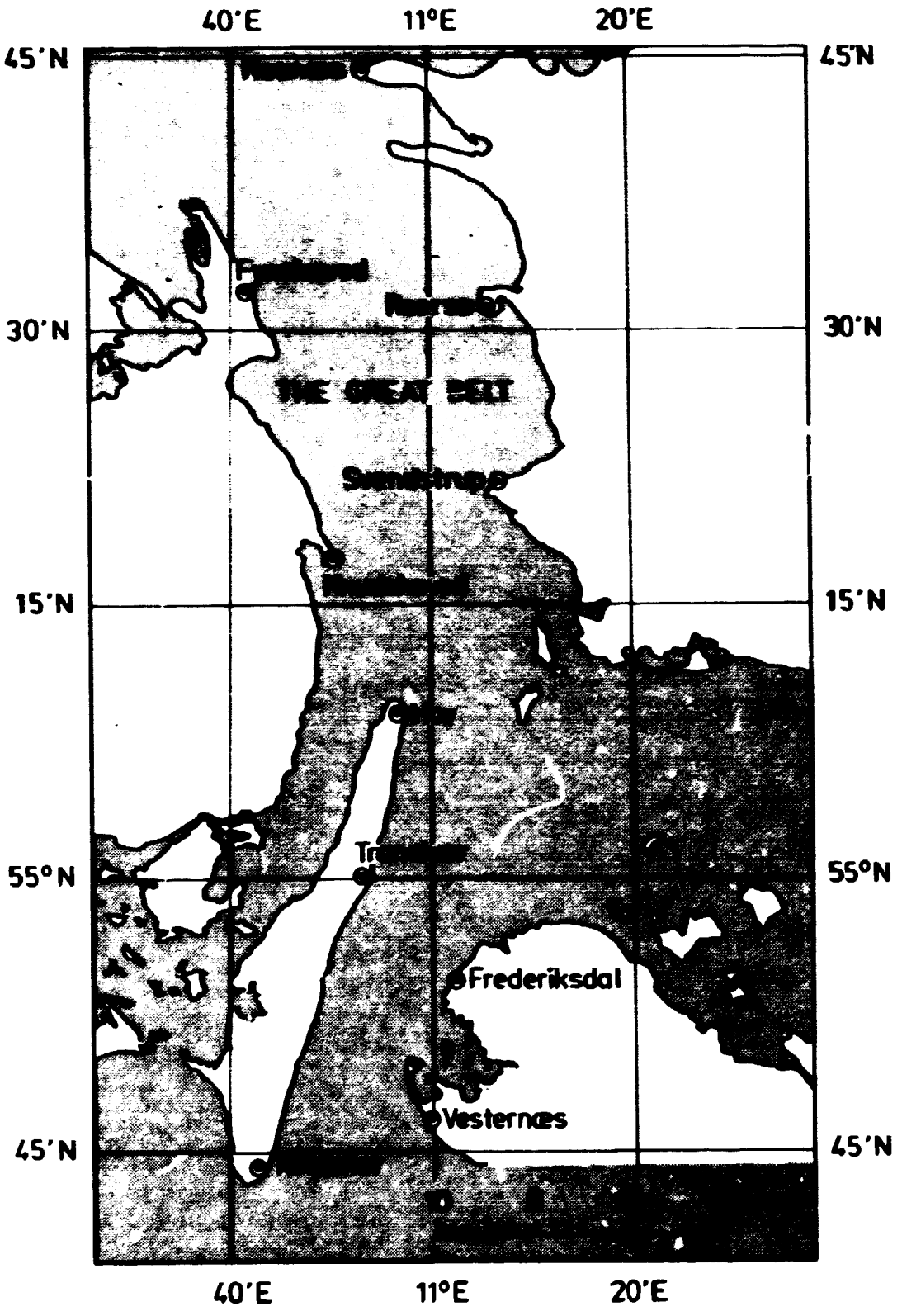

Fig. 9.5.1. The coasts of the Great Belt. Locations for measurements of the background radiation.

Table 9.5.1. TLD-measurements of the background radiation (μR h^{-1}) along the coasts of the Great Belt and Langeland Belt in 1978

Location	Winter 1977-1978	Summer 1978	Mean
Røsnæs	7.6	7.4	7.5
Reersø	8.9	9.2	9.1
Svendstrup	8.0	8.0	8.0
Frederiksdal	-	9.1	9.1
Vesternæs	9.1	9.1	9.1
Kelds Nor	10.1	9.6	9.9
Tranekær	9.3	9.1	9.2
Hov	7.4	7.9	7.7
Fyns Hoved	-	8.3	8.3
Knuds Hoved	8.1	8.3	8.2
Mean	8.6	8.6	8.6

9.6. The Baltic island, Bornholm

Locations on the island Bornholm have been monitored with TLD's during summer 1978. The results and locations are shown in table 9.6.1 and fig. 9.6.1, respectively.

9.7. Discussion

The slight overresponse of the TLD results as compared to the ionization chamber results is discussed elsewhere[31].

Table 9.6.1. TLD measurements of the background radiation (μR h^{-1}) on the island Bornholm in 1978

Location	Summer 1978
1	9.6
2	7.0
3	7.5
4	9.3
5	14.0
Mean	9.5

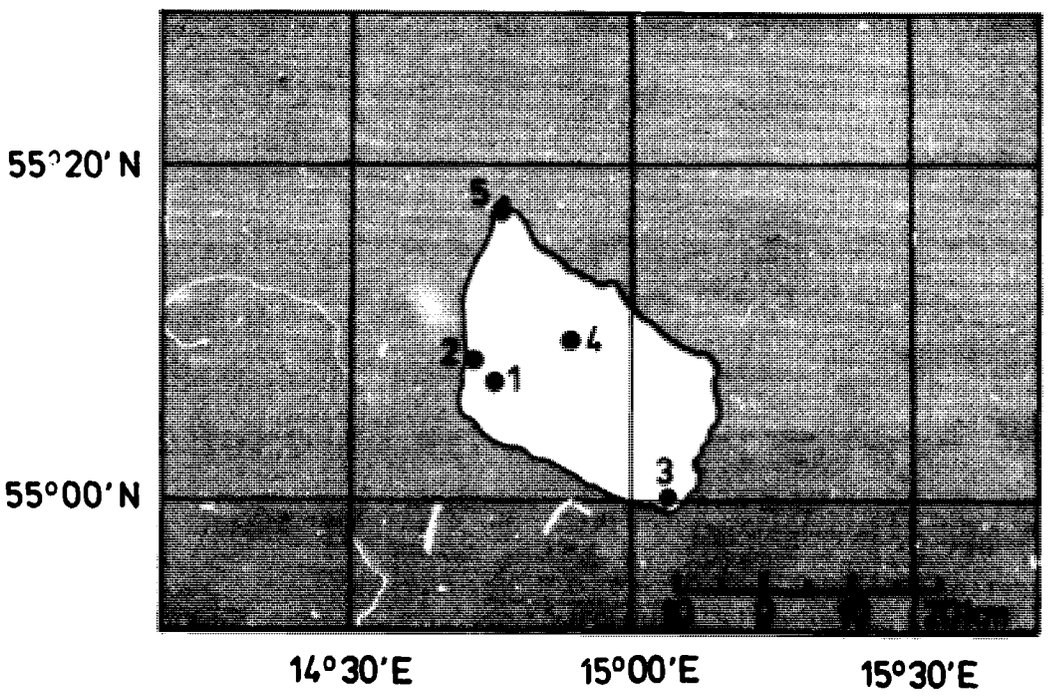

Fig. 9.6.1. Locations for measurements on Bornholm.

10. CONCLUSION

10.1. Environmental monitoring at Risø, Barbebäck and Ringhals

No radioactive contamination of the environment originating from the operation of the research establishment was ascertained outside Risø in 1978. As in previous years, the variations in contamination level were independent of the distance of the sampling locations from Risø.

Benthic brown algae and mussels collected at the Swedish nuclear plants at Barsebäck and Ringhals were used as biological indicators of radioactive pollution. Transfer factors to Fucus were calculated. At Barsebäck Fucus did not distinguish between radiocobalt, ^{65}Zn and ^{54}Mn at Ringhals the transfer factors for Zn seems to be higher than that of cobalt. The discharged cobalt isotopes were integrated over 4-12 months in Fucus vesiculosus. As compared to mussels, brown algae contain approximately 3 times higher concentrations of the various radionuclides.

10.2. Nuclear-weapon debris in the abiotic environment

The mean content of ^{90}Sr in air collected in 1978 was 1.1 fCi $^{90}Sr\ m^{-3}$, i.e. approx. 1.6 times the 1977 level. The average fallout at the State experimental farms in 1978 was 0.46 mCi $^{90}Sr\ km^{-2}$ or 1.2 times the 1977 figure, and the mean concentration of ^{90}Sr in rain water was 0.83 pCi $^{90}Sr\ l^{-1}$.

By the end of 1978 the accumulated fallout was approx. 49 mCi $^{90}Sr\ km^{-2}$. The corresponding ^{137}Cs was estimated at 79 mCi km^{-2}.

In agreement with the greater precipitation in that part of the country, fallout levels in Jutland were 15-25% higher than levels found in eastern Denmark.

The median level of ^{90}Sr in Danish ground water was 12 fCi ^{90}Sr l^{-1}.

Inner Danish surface waters (salinity 16 o/oo) contained 0.7 pCi ^{90}Sr l^{-1} and 1.0 pCi ^{137}Cs l^{-1}, i.e. for ^{90}Sr unchanged as compared with 1977, but for ^{137}Cs approx. 20% higher than in 1977.

10.3. Fallout nuclides in the human diet

The mean level of ^{90}Sr in Danish milk was 3.2 S.U., and the mean content of ^{137}Cs was approx. 7.0 pCi ^{137}Cs l^{-1}.

The 1978 ^{90}Sr and ^{137}Cs levels were 1.1 and 1.4 times higher respectively than the levels found in milk produced in 1977.

The ^{90}Sr mean content in grain from the 1978 harvest was 24 pCi ^{90}Sr kg^{-1}. The ^{137}Cs mean content in grain was 27 pCi ^{137}Cs kg^{-1}. The ^{90}Sr level in grain from the 1978 harvest was 10% lower than the level found in the 1977 harvest, and ^{137}Cs was 1.2 times the 1977 level.

The mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1978 were 7 pCi ^{90}Sr kg^{-1} (22 S.U.) and 2 pCi ^{137}Cs kg^{-1}, respectively, and in fruits 0.9 pCi ^{90}Sr kg^{-1} and 3.2 pCi ^{137}Cs kg^{-1}; potatoes contained 2.0 pCi ^{90}Sr kg^{-1} and 3.8 pCi ^{137}Cs kg^{-1}.

The mean levels of ^{90}Sr and ^{137}Cs in total-diet samples collected in 1978 were 4.3 S.U., or 7 pCi ^{90}Sr day^{-1} and 15 pCi ^{137}Cs day^{-1}, respectively. From analyses of the individual diet components, the ^{90}Sr level in the Danish average diet was estimated to be 4.4 S.U. and the ^{137}Cs intake to be 18 pCi ^{137}Cs day^{-1}. The levels of ^{90}Sr and ^{137}Cs in the Danish total diet consumed in 1978 were 15% and 45% higher respectively than the levels observed in 1977.

Grain products contributed 36% and milk products 32% to the total ^{90}Sr intake; 30% of the ^{137}Cs in the diet originated from meat, 21% from grain products, and 19% from milk products.

Both ^{90}Sr and ^{137}Cs diet levels were on the average higher in Jutland than in eastern Denmark.

10.4. Strontium-90 and Cesium-137 in humans

The ^{90}Sr mean content in human bone (vertebrae) collected in 1978 was about 1 S.U. in all age groups. The 1978 bone levels were similar to the 1977 levels.

The mean content of ^{137}Cs in the human body in 1978 was estimated from whole-body countings to be 2 nCi (15 pCi ^{137}Cs $(g\ K)^{-1}$, i.e. 1.7 times higher than the 1977 level.

10.5. Tritium in environmental samples

Tritium levels varied between 0.2 and 0.7 nCi l^{-1} in rain water and between 0.1 and 0.3 nCi l^{-1} in ground water. The variation with time in rain water corresponded to the equivalent variation in ^{90}Sr levels.

10.6. Plutonium in environmental samples

Plutonium was determined in soil, sediments and seaweed. The main source of plutonium in these samples was nuclear weapons fallout, however minor contributions of Pu from reprocessing plants to the levels observed in seaweed samples were possible.

10.7. Background radiation

The average total background exposure rate measured with the ionization chamber at the State experimental farms was 7.6 μR h^{-1} of which 3.6 μR h^{-1} originates from the secondary cosmic radiation and the remaining 4 μR h^{-1} from terrestrial sources.

ACKNOWLEDGEMENTS

The authors wish to thank Miss Anna Holm Pedersen, Mrs. Karen Mandrup Jensen, Miss Karen Wie Nielsen, Mrs. Jytte Lene Clausen, Mrs. Anna Madsen, Mrs. Pearl Baade Pedersen, Mrs. Alice Kjølhede, Mrs. Else Sørensen and Mr. Michael Brandt Svendsen for their conscientious performance of the analyses. We are grateful to Mr. Peder Kristiansen and Mr. Gunnar Bitsch for collection of the samples and performance of the γ-background measurements. We thank Mrs. Lis Sørensen for careful work with the TL dosimeters.

We are specially indebted to the staffs of the eleven State experimental farms at Tylstrup, Ødum, Studsgård, Askov, Si Jyndevad, Blangstedgård, Tystofte, Ledreborg, Virumgård, Abed, and Åkirkeby, who have continued to supply us with a number of the most important samples dealt with in this report.

Finally we convey our thanks to M/S "Nordsøen" in Esbjerg and M/S "Nordjylland" in Skagen for the sea water samples received from the North Sea.

Appendix A. Calculated fallout in the eight zones in 1978

Zone	mm precipitation in 1978	mCi ^{90}Sr km^{-2} in 1978	Accumulated mCi ^{90}Sr km^{-2} by the end of 1978
I: N. Jutland II: E. Jutland III: W. Jutland IV: S. Jutland	721 (773)	0.54	55
V: Funen VI: Zealand VII: Lolland-Falster	611 (614)	0.38	44
VIII: Bornholm	561 (605)	0.42	-
Area-weighted mean	688 (726)	0.49	52

The amounts of precipitation were obtained from ref. 9. The ^{90}Sr deposition was estimated from 4.2 and appendix D.

The precipitations in brackets were the mean of values measured by the Meteorological Institute at the State experimental farms: Jutland: Tylstrup, Ødum, Studsgård, Askov, St. Jyndevad; The Islands: Blangstedgård, Tystofte, Virumgård, Abed; Bornholm: Åkirkeby.

APPENDIX B. Statistical information

Zone		Area in km^2 15) 1971	Population in thousands 28) 1976	Annual milk production in mega-kg 14) 1971	Annual wheat production in mega-kg 13) 1972	Annual rye production in mega-kg 13) 1972	Annual potato production in mega-kg 13) 1972	Vegetable area in km^2 13) 1972
I:	N. Jutland	6,171	471	911				
II:	E. Jutland	7,561	881	1,258	145	155	609	14
III:	W. Jutland	12,104	687	926				
IV:	S. Jutland	3,929	245	572				
V:	Funen	3,486	446	393				
VI:	Zealand	7,435	2,165*	395				
VII:	Lolland-Falster	1,795	123	68	448	71	100	73
VIII:	Bornholm	588	47	39				
Total		43,069	5,065	4,562	593	226	709	87

*1,270,000 people were living in Greater Copenhagen and 895,000 in the remaining part of Zealand.

APPENDIX C

The mean ratio between observed and predicted values was 0.99 ± 0.33 (1 SD) for ^{90}Sr and 1.25 ± 0.35 for ^{137}Cs. In general, the prediction models overestimated the ^{90}Sr levels in 1978, while the ^{137}Cs concentrations were underestimated. This was also the case in 1977. An explanation of the higher ^{137}Cs levels observed, compared with those expected from the prediction models was given in Risø Report No. 386[1] Appendix C.

This explanation seems reasonable also for 1978 as the $^{137}Cs/^{90}Sr$ ratio this year was 2.8 (4.1.2) and not as assumed in the predictions 1.6.

Appendix C.1. Comparison between observed and predicted ^{90}Sr levels in environmental samples collected in 1978

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	pCi ^{90}Sr (g Ca)$^{-1}$	3.8	4.6	0.83	C.3.2.1 No. 1
" "	Islands	- " -	2.4	2.4	1.00	- " - No. 3
Rye	Jutland	pCi ^{90}Sr kg^{-1}	32	22	1.45	C.2.2.1 No. 1
"	Islands	- " -	13.8	11.3	1.22	- " - No. 3
Barley	Jutland	- " -	27	26	1.04	- " - No. 4
"	Islands	- " -	17.1	13.4	1.28	- " - No. 6
Wheat	Jutland	- " -	39	27	1.44	- " - No. 8
"	Islands	- " -	17.7	13.9	1.27	- " - No.10
Oats	Jutland	- " -	26	47	0.55	- " - No.12
"	Islands	- " -	22	24	0.92	- " - No.13
Rye bread	Denmark	- " -	14.6	16.4	0.89	C.2.3.1 No. 1
White bread	"	- " -	5.0	4.4	1.14	- " - No. 2
Potatoes	Jutland	- " -	2.3	3.2	0.72	C.2.5.1 No. 8
"	Islands	- " -	1.6	2.8	0.57	- " - No.10
Cabbage	Jutland	- " -	8.4	10.1	0.83	- " - No. 1
"	Islands	- " -	6.2	8.7	0.71	- " - No. 3
Carrot	Jutland	- " -	12.1	17.0	0.71	- " - No. 5
"	Islands	- " -	10.3	7.7	1.34	- " - No. 6
Apples	Denmark	- " -	0.92	0.88	1.05	C.2.5.1 No.13
Pork	"	- " -	1.23	0.95	1.29	C.3.4.1 No. 3
Beef	"	- " -	1.10	1.28	0.86	- " - No. 1
Cod	"	- " -	1.07	1.48	0.72	C.3.5.1 No. 1
"Plaice"	"	- " -	0.88	0.75	1.17	- " - No. 5
Eggs	"	- " -	0.45	0.80	0.56	C.3.6.1 No. 6
Total diet C	"	pCi ^{90}Sr (g Ca)$^{-1}$	4.4	5.4	0.81	C.4.2.1 No. 1
" " P	"	- " -	4.4	4.9	0.90	- " - No. 7
Human bone > 29 yr	"	- " -	1.08	1.22	0.89	C.4.3.1 No.13
Whole year grass	Islands	- " -	53	27	1.96	C.2.4.1 No. 1
Fucus Vesiculosus	"	- " -	6.2	13.8	0.45	C.2.7.1 No. 3
Zostera Marina	"	- " -	2.9	2.5	1.16	- " - No. 1
Ground water	Denmark	fCi ^{90}Sr l^{-1}	8.9	10.7	0.83	C.1.4.1 No. 1

*May 1978 - April 1979 ("milk year" (21)).

Appendix C.2. Comparison between observed and predicted ^{137}Cs levels in environmental samples collected in 1978

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	pCi ^{137}Cs $(g\ K)^{-1}$	5.2	4.2	1.24	C.3.2.2 No. 1
" "	Islands	- " -	3.0	2.3	1.30	- " - No. 3
Rye	Jutland	pCi ^{137}Cs kg^{-1}	50	35	1.43	C.2.2.4 No. 2
"	Islands	- " -	29	23	1.26	- " - No. 3
Barley	Jutland	- " -	31	28	1.11	- " - No. 4
"	Islands	- " -	19.8	15.8	1.25	- " - No. 5
Wheat	Jutland	- " -	26	28	0.93	- " - No. 6
"	Islands	- " -	16.1	13.5	1.19	- " - No. 7
Oats	Jutland	- " -	26	23	1.13	- " - No. 8
"	Islands	- " -	22	15	1.47	- " - No. 9
Rye bread	Denmark	- " -	17.8	22	0.81	C.2.3.1 No. 4
White bread	"	- " -	7.2	4.9	1.47	- " - No. 5
Potatoes	Jutland	- " -	5.0	6.4	0.78	C.2.5.3 No. 5
"	Islands	- " -	2.6	2.2	1.18	- " - No. 7
Cabbage	Denmark	- " -	1.71	1.94	0.88	- " - No. 1
Carrot	"	- " -	1.66	1.49	1.11	- " - No. 3
Apples	"	- " -	3.2	2.6	1.23	- " - No.11
Pork	"	- " -	38	23	1.65	C.3.4.2 No. 3
Beef	"	- " -	28	22	1.27	- " - No. 1
Eggs	"	- " -	1.34	1.75	0.77	C.3.6.2 No. 6
Total diet C	"	pCi ^{137}Cs $(g\ K)^{-1}$	4.0	2.4	1.67	C.4.2.2 No. 1
" " P	"	- " -	4.7	3.6	1.31	- " - No. 6
Human body	"	- " -	14.6	6.2	2.35	C.4.5.1 No. 1

*(cf. note to appendix C.1)

APPENDIX D

d_i:

Annual fallout rate in mCi ^{90}Sr km^{-2} y^{-1}.

Accumulated fallout by the end of the year (i) assuming effective half-lives of ^{90}Sr of 27.7 y. Unit: mCi ^{90}Sr km^{-2}.

$d_{i(May-Aug.)}$ and $d_{i(July-Aug.)}$:

The fallout rates in the periods: May-Aug. and July-Aug., respectively. Unit: mCi ^{90}Sr km^{-2} $period^{-1}$.

The fallout rate (d_i) was based on precipitation data collected for all Denmark in the period 1962-1978 (cf. table 4.2.1[1]). Before 1962 the levels in the tables were estimated from the HASL data for New York (HASL Appendix 291, 1975)[29] considering that the mean ratio between ^{90}Sr fallout in Denmark and New York was 0.7 in the period 1962-1974.

The $d_{i(May-Aug.)}$ and $d_{i(July-Aug.)}$ values were also obtained from table 4.2.1[1] for the period 1962-1978. For the years 1959-1961 the values were calculated from data obtained from ^{90}Sr analysis of air (1959) and precipitation samples (1962 and 1961) collected at Risø. Before 1959, the values were estimated from the corresponding d_i values assuming that the ratios $d_{i(May-Aug.)}/d_i$ and $d_{i(July-Aug.)}/d_i$ were constant in time and equal to the means found for the period 1962-1974, which were 0.54 (1 S.D.: 0.09) and o.24 (1 S.D.: 0.06), respectively.

APPENDIX D. Fallout rates and accumulated fallout (mCi ^{90}Sr km^{-2}) in Denmark 1950–1978

	Denmark		Jutland		Islands	
	di	$Ai_{(27.7)}$	di	$Ai_{(27.7)}$	di	$Ai_{(27.7)}$
1950	0.021	0.020	0.022	0.021	0.020	0.020
1951	0.101	0.110	0.114	0.132	0.088	0.105
1952	0.198	0.309	0.224	0.347	0.172	0.270
1953	0.500	0.789	0.566	0.891	0.434	0.687
1954	1.901	2.623	2.152	2.967	1.650	2.279
1955	2.501	4.997	2.831	5.655	2.171	4.348
1956	3.101	7.898	3.518	8.939	2.692	6.858
1957	2.181	10.728	3.518	12.142	2.692	9.313
1958	4.302	14.658	4.869	16.591	3.734	12.725
1959	6.102	20.247	6.908	22.918	5.297	17.576
1960	1.140	20.859	1.291	23.610	0.990	18.107
1961	1.481	21.787	1.676	24.661	1.285	18.913
1962	7.428	28.493	7.976	31.830	6.880	25.155
1963	16.695	44.071	18.453	49.041	14.937	39.101
1964	10.412	53.136	11.685	59.225	9.139	47.048
1965	3.954	55.679	4.204	61.861	3.704	49.497
1966	2.145	56.395	2.166	62.445	2.124	50.345
1967	1.047	56.023	1.176	62.048	0.918	49.997
1968	1.401	56.006	1.568	62.345	1.237	49.968
1969	1.035	55.632	1.241	61.721	0.829	49.542
1970	1.647	55.863	1.993	62.140	1.301	49.586
1971	1.506	55.951	1.726	62.288	1.286	49.615
1972	0.435	54.993	0.457	61.194	0.413	48.792
1973	0.192	53.821	0.215	59.891	0.168	47.750
1974	0.710	53.183	0.779	59.171	0.643	47.197
1975	0.414	52.272	0.452	58.150	0.376	46.397
1976	0.103	51.082	0.116	56.826	0.090	45.339
1977	0.384	50.204	0.405	55.827	0.362	44.581
1978	0.463	49.426	0.538	54.985	0.388	43.867

Denmark		Jutland		Islands	
$di_{(May-Aug)}$	$di_{(July-Aug)}$	$di_{(May-Aug)}$	$di_{(July-Aug)}$	$di_{(May-Aug)}$	$di_{(July-Aug)}$
0.01	0.01	0.01	0.01	0.01	0.01
0.05	0.02	0.06	0.03	0.05	0.02
0.11	0.05	0.12	0.05	0.09	0.04
0.27	0.12	0.31	0.14	0.23	0.10
1.03	0.46	1.16	0.52	0.89	0.40
1.35	0.60	1.53	0.68	1.17	0.52
1.67	0.74	1.90	0.84	1.45	0.65
1.67	0.74	1.90	0.84	1.45	0.65
2.32	1.03	2.63	1.17	2.02	0.90
2.50	0.68	2.76	0.75	2.24	0.61
0.47	0.31	0.52	0.34	0.42	0.28
0.66	0.47	0.73	0.52	0.59	0.42
4.223	1.857	4.566	2.052	3.880	1.662
9.965	5.629	10.753	5.932	9.177	5.327
6.235	2.568	7.170	2.910	5.299	2.226
2.029	0.850	2.094	0.852	1.964	0.848
1.049	0.418	0.984	0.496	1.114	0.340
0.367	0.141	0.380	0.134	0.354	0.148
0.848	0.426	0.910	0.460	0.786	0.392
0.614	0.276	0.723	0.319	0.505	0.233
0.908	0.547	1.076	0.632	0.740	0.462
0.992	0.405	1.154	0.516	0.830	0.294
0.253	0.084	0.262	0.084	0.244	0.084
0.075	0.033	0.093	0.039	0.057	0.027
0.421	0.190	0.463	0.219	0.378	0.162
0.159	0.075	0.179	0.091	0.157	0.060
0.032	0.010	0.032	0.011	0.032	0.009
0.178	0.107	0.164	0.085	0.190	0.129
0.232	0.096	0.275	0.098	0.188	0.093

REFERENCES

1) Risø Reports Nos. 1, 3, 9, 14, 23, 41, 63, 85, 107, 130, 154, 180, 201, 220, 245, 265, 291, 305, 323, 345, 361 and 386 (1957-78).
2) R.G. Osmond, M.J. Owers, C. Healy, and A.P Mead, The Determination of Radioactivity due to Caesium, Strontium, Barium and Cerium in Waters and Filters. AERE-R 2899 (1959).
3) F.J. Bryant, A. Morgan, and G.S. Spicer, The Determination of Radiostrontium in Biological Materials. AERE-R 3030 (1959).
4) John H. Harley, Manual of Standard Procedures. HASL-300 (1972).
5) A. Hald, private communication (1958).
6) J. Lippert, Low Level Counting. Risø Report No. 44 (1963).
7) P. Quittner, Nucl. Instr. and Methods 76, 115-124 (1969).
8) J. Lippert, Some Applications for Semiconductor Detectors in Health Physics. Proc. of the First International Congress of Radiation Protection, 271-277 (Pergamon Press,1968).
9) Meteorologisk Institut, Ugeberetning om nedbør m.m. 1978.
10) S.L. Kupferman, V.T. Bowen, H.D. Livingstone and A. Aarkrog. Radioactive effluent from Windscale as a perturbation of the fallout tracer experiment in the north Atlantic Ocean. Submitted for publication in Earth Planet. Sci. Lett. (1979).
11) Folmer Dam and Agnes Elgström, Vore fødemidier (Svegårds Forlag, Sorø, 1968).
12) J. Vestergaard, Analysis of Variance with Unequal Numbers in Group. GIER System Library No. 211 (A/S Regnecentralen, Copenhagen, 1964).
13) Landbrugsstatistik 1975. Danmarks Statistik (Copenhagen, 1977).
14) Fortegnelse over samtlige mejerier og mejeriorganisationer i Danmark (Århus, 1972).
15) Statistisk årbog 1972 (Statistical Yearbook) (Copenhagen, 1972).
16) J. Lippert, Statdata, Risø-M-1780, June 1975.

17) A. Melhuus, K.L. Seip, H.M. Seip and S. Myklestad, A preliminary study of the use of Benthic Algae as biological indicators of heavy Metal pollution in Sørfjorden, Norway. Environ. Pollut. 15, 101-107 (1978).

18) Ebbe Kanneworff and Willy Nicolaysen, The "HAPS". A Frame-supported Bottom Corer. Ophelia 10:119-129 (Oct. 1973).

19) N.A. Talvite, Analyt. Chem. 43, 1827 (1971).

20) M.L. Young, The transfer of ^{65}Zn and ^{59}Fe along a Fucus serratus (L.) Littorina obtusata (L.) Food Chain. J. mar. biol. Ass. U.K. 55, 583-610 (1975).

21) A. Aarkrog, Environmental Studies on Radioecological Sensitivity and Variability with Special Emphasis on the Fallout Nuclides ^{90}Sr and ^{137}Cs. (To be published, 1980).

22) J. Brolund Larsen and S. Klausen, Foderplaner for malkekøer, 11. Ed. (Landhusholdningsselskabet, Copenhagen). 30 pp. (1969).

23) L. Bøtter-Jensen, A TLD environmental gamma monitoring system with automatic processing. (To be published 1979).

24) S.P. Nielsen, In situ measurements of environmental gamma radiation using a mobile Ge(Li) spectrometer system. Risø Report No. 367 (1977).

25) UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. (New York) 725 pp. (1977).

26) P. Theodorson, Improved Tritium Counting through High Electrolytic Enrichment, Int. f. Appl. Radiat. Isotopes 25 (1974). 97-104 pp.

27) J.F. Cameron and B.R. Payne, Proc. of the 6. International Conference on Radiocarbon and Tritium. Dating, Pullmann, Washington, June 7-11 1965, 454 pp. Conf. - 650652 mikro.

28) Statistisk årbog 1977 (Statistical Yearbook) (Copenhagen 1978).

29) HASL 291 Appendix, 1975.

30) N.A. Talvitie. Electrodeposition af Actinides for Alpha Spectrometric Determination. Analytical Chemistry, 44, pp. 280. February 1972.

31) S.P. Nielsen and L. Bøtter-Jensen, Intercomparison of Instruments for Measurements of Background Radiation. (To be published 1980).

32) A. Aarkrog, H. Dahlgaard, M. Edgren, E. Holm, S. Mattsson, Karen Nilsson, B. Persson.
Upptag av naturlig och artificiell aktivitet i blåstång utanför Barsebäck och Ringhals kärnkraftverk.
Det andet Nordiske Radioøkologiseminar Helsingør 8-10 maj 1979, Danmark (in Scandinavian).

33) H. Dahlgaard. Evaluation of bioindicators for monitoring radioactive pollution of estuarine and marine environments. Second International Symposium of Radioecology Cadarache, France, 19-22 June, 1979.

34) Sveriges Meteorologiska och Hydrologiska Institut,: Oceanografiska Kontrollundersökningar utanför Barsebäcks Kärnkraftstation 1978 (in Swedish).

35) Sydkraft: Månedsrapport, and Vattenfall: Rapport över luft- och vätskeburna utsläpp,...Ringhals. (Monthly reports to the Swedish authorities on discharges from Barsebäck and Ringhals, respectively) (in Swedish).

Sales distributors:
Jul. Gjellerup, Sølvgade 87,
DK-1307 Copenhagen K, Denmark

Available on exchange from:
Risø Library, Risø National Laboratory,
P. O. Box 49, DK-4000 Roskilde, Denmark

ISBN 87-550-0594-2
ISSN 0106-2840